Tipping elements
Systems with critical thresholds, beyond which small perturbations in forcing can—as a result of positive feedbacks—lead to large, nonlinear, and irreversible shifts in state. In the climate system, a tipping element is a subcomponent of the climate system (typically at a spatial scale of approximately 1,000 km or larger). (*CSSR, Ch. 15*)

Tipping point
The critical **threshold** of a tipping element. Some limit its use to critical thresholds in which both the commitment to change and the change itself occur without a significant lag, while others also apply it to situations where a commitment occurs rapidly, but the committed change may play out over centuries and even millennia. (*CSSR, Ch. 15*)

Transient climate response
See **climate sensitivity**.

Tropopause
The boundary between the troposphere and the stratosphere. (IPCC AR5 WGI Annex III: Glossary)

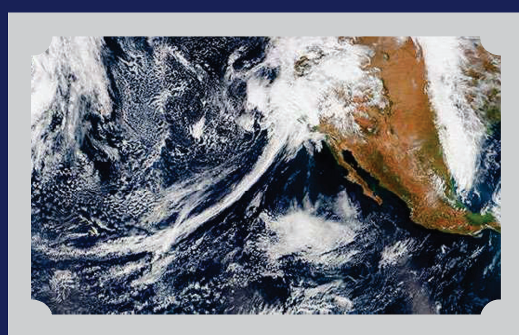
Uncertainty
A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (for example, a probability density function) or by qualitative statements (for example, reflecting the judgment of a team of experts) (cut from IPCC AR5 WGII Annex II: Glossary).

Given that no model can represent the world with complete accuracy, **structural model uncertainty** refers to how well the physical processes of the real world are represented in the structure of a model. Different modeling research groups will represent the climate system in different ways, and to some extent this decision is a subjective judgement. The use of climate **model ensembles** can address the uncertainty of differently structured models. (adapted from *UK Met Office, Climate Projections*, Glossary)

In contrast, **parametric uncertainty** refers to incomplete knowledge about real world processes in a climate model. A parameter is well-specified in that it has a true value, even if this value is unknown. Such empirical quantities can be measured, and the level of uncertainty about them can be represented in probabilistic terms. (adapted from *Morgan and Henrion, 1990, pp 50-52*)

Urban heat island effect
The relative warmth of a city compared with surrounding rural areas, associated with changes in runoff, effects on heat retention, and changes in surface albedo. (IPCC AR5 WGI Annex III: Glossary)

Zonal mean
Data average along a latitudinal circle on the globe.



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Climate Change 2014
Synthesis Report
Summary for Policymakers

Introduction

This Synthesis Report is based on the reports of the three Working Groups of the Intergovernmental Panel on Climate Change (IPCC), including relevant Special Reports. It provides an integrated view of climate change as the final part of the IPCC's Fifth Assessment Report (AR5).

This summary follows the structure of the longer report which addresses the following topics: Observed changes and their causes; Future climate change, risks and impacts; Future pathways for adaptation, mitigation and sustainable development; Adaptation and mitigation.

In the Synthesis Report, the certainty in key assessment findings is communicated as in the Working Group Reports and Special Reports. It is based on the author teams' evaluations of underlying scientific understanding and is expressed as a qualitative level of confidence (from *very low* to *very high*) and, when possible, probabilistically with a quantified likelihood (from *exceptionally unlikely* to *virtually certain*)[1]. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers.

This report includes information relevant to Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC).

SPM 1. Observed Changes and their Causes

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems. *{1}*

SPM 1.1 Observed changes in the climate system

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen. *{1.1}*

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period from 1983 to 2012 was *likely* the warmest 30-year period of the last 1400 years in the Northern Hemisphere, where such assessment is possible (*medium confidence*). The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06] °C[2] over the period 1880 to 2012, when multiple independently produced datasets exist (Figure SPM.1a). *{1.1.1, Figure 1.1}*

In addition to robust multi-decadal warming, the globally averaged surface temperature exhibits substantial decadal and interannual variability (Figure SPM.1a). Due to this natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. As one example, the rate of warming over

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[1] Each finding is grounded in an evaluation of underlying evidence and agreement. In many cases, a synthesis of evidence and agreement supports an assignment of confidence. The summary terms for evidence are: limited, medium or robust. For agreement, they are low, medium or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, e.g., *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, more unlikely than likely 0–<50%, extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*. See for more details: Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L. Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.-K. Plattner, G.W. Yohe and F.W. Zwiers, 2010: Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties, Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland, 4 pp.

[2] Ranges in square brackets or following '±' are expected to have a 90% likelihood of including the value that is being estimated, unless otherwise stated.

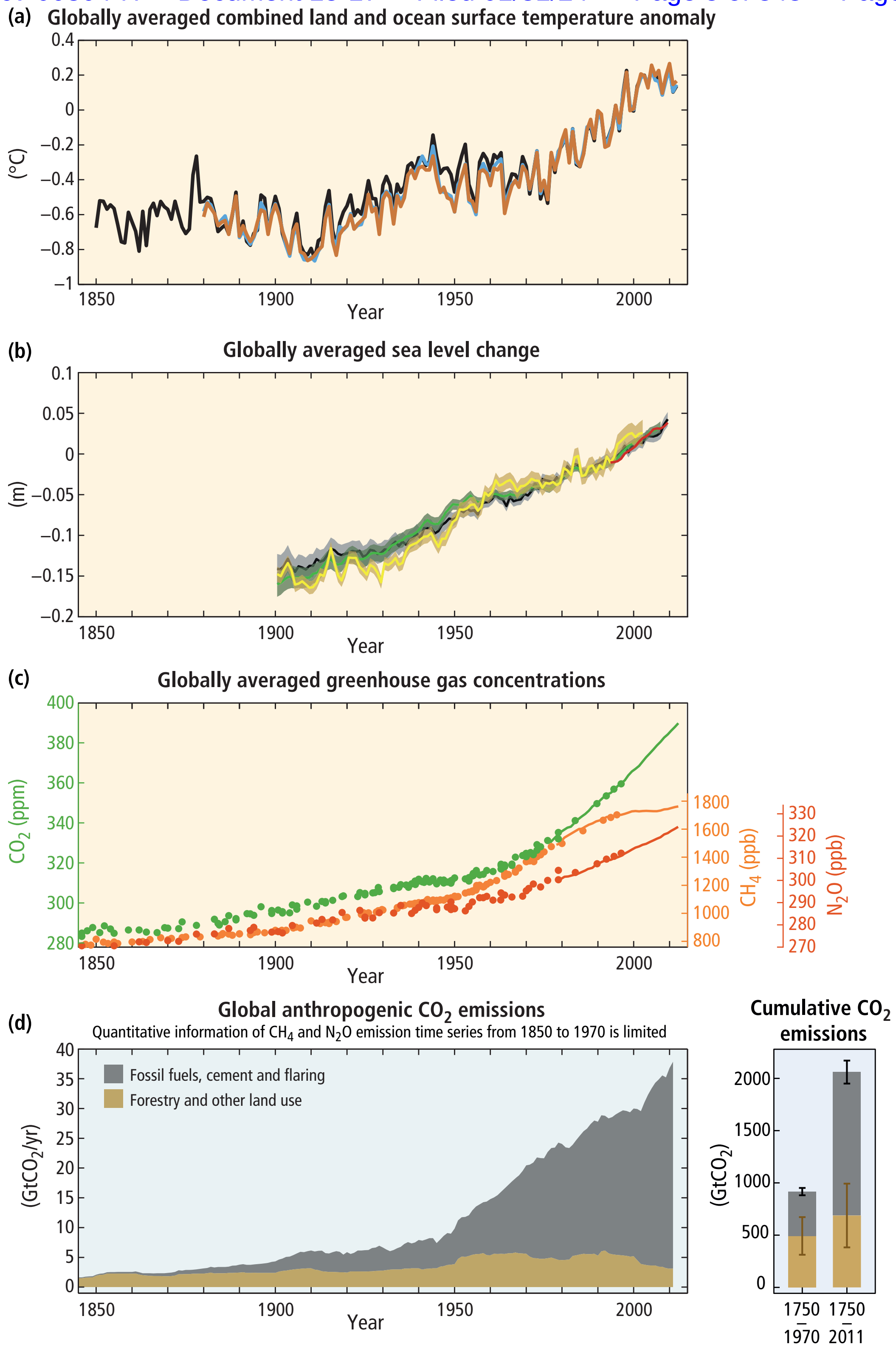

Figure SPM.1 | The complex relationship between the observations (panels a, b, c, yellow background) and the emissions (panel d, light blue background) is addressed in Section 1.2 and Topic 1. Observations and other indicators of a changing global climate system. Observations: **(a)** Annually and globally averaged combined land and ocean surface temperature anomalies relative to the average over the period 1986 to 2005. Colours indicate different data sets. **(b)** Annually and globally averaged sea level change relative to the average over the period 1986 to 2005 in the longest-running dataset. Colours indicate different data sets. All datasets are aligned to have the same value in 1993, the first year of satellite altimetry data (red). Where assessed, uncertainties are indicated by coloured shading. **(c)** Atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2, green), methane (CH_4, orange) and nitrous oxide (N_2O, red) determined from ice core data (dots) and from direct atmospheric measurements (lines). Indicators: **(d)** Global anthropogenic CO_2 emissions from forestry and other land use as well as from burning of fossil fuel, cement production and flaring. Cumulative emissions of CO_2 from these sources and their uncertainties are shown as bars and whiskers, respectively, on the right hand side. The global effects of the accumulation of CH_4 and N_2O emissions are shown in panel c. Greenhouse gas emission data from 1970 to 2010 are shown in Figure SPM.2. *{Figures 1.1, 1.3, 1.5}*

the past 15 years (1998–2012; 0.05 [–0.05 to 0.15] °C per decade), which begins with a strong El Niño, is smaller than the rate calculated since 1951 (1951–2012; 0.12 [0.08 to 0.14] °C per decade). *{1.1.1, Box 1.1}*

Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*), with only about 1% stored in the atmosphere. On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 [0.09 to 0.13] °C per decade over the period 1971 to 2010. It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010, and it *likely* warmed between the 1870s and 1971. *{1.1.2, Figure 1.2}*

Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (*medium confidence* before and *high confidence* after 1951). For other latitudes, area-averaged long-term positive or negative trends have *low confidence*. Observations of changes in ocean surface salinity also provide indirect evidence for changes in the global water cycle over the ocean (*medium confidence*). It is *very likely* that regions of high salinity, where evaporation dominates, have become more saline, while regions of low salinity, where precipitation dominates, have become fresher since the 1950s. *{1.1.1, 1.1.2}*

Since the beginning of the industrial era, oceanic uptake of CO_2 has resulted in acidification of the ocean; the pH of ocean surface water has decreased by 0.1 (*high confidence*), corresponding to a 26% increase in acidity, measured as hydrogen ion concentration. *{1.1.2}*

Over the period 1992 to 2011, the Greenland and Antarctic ice sheets have been losing mass (*high confidence*), *likely* at a larger rate over 2002 to 2011. Glaciers have continued to shrink almost worldwide (*high confidence*). Northern Hemisphere spring snow cover has continued to decrease in extent (*high confidence*). There is *high confidence* that permafrost temperatures have increased in most regions since the early 1980s in response to increased surface temperature and changing snow cover. *{1.1.3}*

The annual mean Arctic sea-ice extent decreased over the period 1979 to 2012, with a rate that was *very likely* in the range 3.5 to 4.1% per decade. Arctic sea-ice extent has decreased in every season and in every successive decade since 1979, with the most rapid decrease in decadal mean extent in summer (*high confidence*). It is *very likely* that the annual mean Antarctic sea-ice extent increased in the range of 1.2 to 1.8% per decade between 1979 and 2012. However, there is *high confidence* that there are strong regional differences in Antarctica, with extent increasing in some regions and decreasing in others. *{1.1.3, Figure 1.1}*

Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m (Figure SPM.1b). The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*). *{1.1.4, Figure 1.1}*

SPM 1.2 Causes of climate change

Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are *extremely likely* to have been the dominant cause of the observed warming since the mid-20th century. *{1.2, 1.3.1}*

Anthropogenic greenhouse gas (GHG) emissions since the pre-industrial era have driven large increases in the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Figure SPM.1c). Between 1750 and 2011, cumulative anthropogenic CO_2 emissions to the atmosphere were 2040 ± 310 $GtCO_2$. About 40% of these emissions have remained in the atmosphere (880 ± 35 $GtCO_2$); the rest was removed from the atmosphere and stored on land (in plants and soils) and in the ocean. The ocean has absorbed about 30% of the emitted anthropogenic CO_2, causing ocean acidification. About half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years (*high confidence*) (Figure SPM.1d). *{1.2.1, 1.2.2}*

Total annual anthropogenic GHG emissions by gases 1970–2010

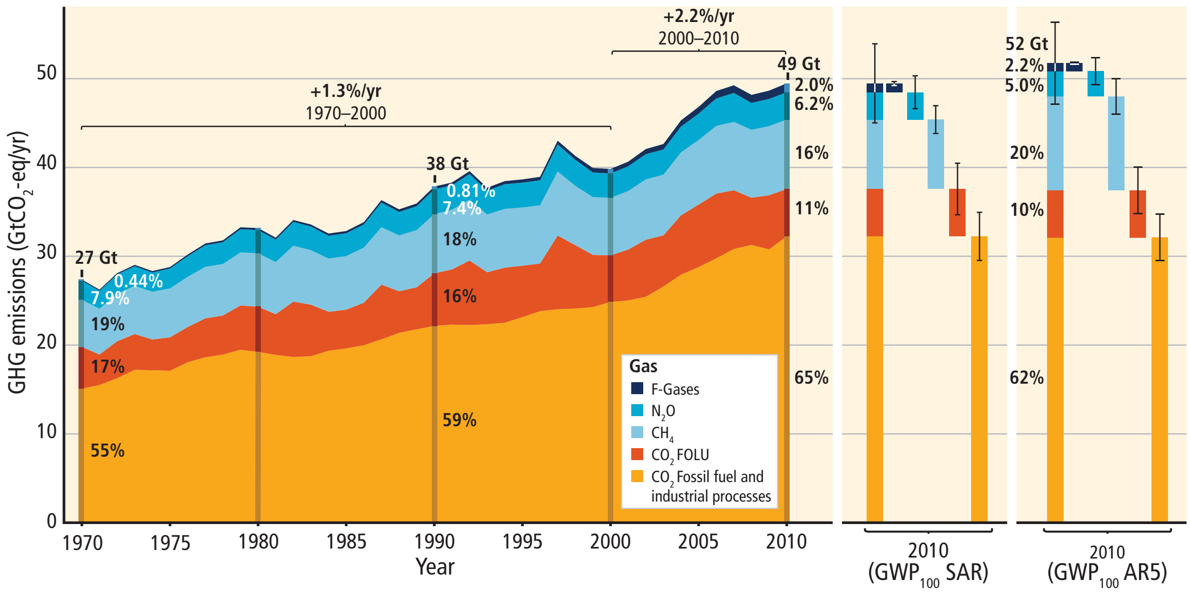

Figure SPM.2 | Total annual anthropogenic greenhouse gas (GHG) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) for the period 1970 to 2010 by gases: CO_2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH_4); nitrous oxide (N_2O); fluorinated gases covered under the Kyoto Protocol (F-gases). Right hand side shows 2010 emissions, using alternatively CO_2-equivalent emission weightings based on IPCC Second Assessment Report (SAR) and AR5 values. Unless otherwise stated, CO_2-equivalent emissions in this report include the basket of Kyoto gases (CO_2, CH_4, N_2O as well as F-gases) calculated based on 100-year Global Warming Potential (GWP_{100}) values from the SAR (see Glossary). Using the most recent GWP_{100} values from the AR5 (right-hand bars) would result in higher total annual GHG emissions (52 $GtCO_2$-eq/yr) from an increased contribution of methane, but does not change the long-term trend significantly. *{Figure 1.6, Box 3.2}*

Total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute increases between 2000 and 2010, despite a growing number of climate change mitigation policies. Anthropogenic GHG emissions in 2010 have reached 49 ± 4.5 $GtCO_2$-eq/yr [3]. Emissions of CO_2 from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emissions increase from 1970 to 2010, with a similar percentage contribution for the increase during the period 2000 to 2010 (*high confidence*) (Figure SPM.2). Globally, economic and population growth continued to be the most important drivers of increases in CO_2 emissions from fossil fuel combustion. The contribution of population growth between 2000 and 2010 remained roughly identical to the previous three decades, while the contribution of economic growth has risen sharply. Increased use of coal has reversed the long-standing trend of gradual decarbonization (i.e., reducing the carbon intensity of energy) of the world's energy supply (*high confidence*). *{1.2.2}*

The evidence for human influence on the climate system has grown since the IPCC Fourth Assessment Report (AR4). It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period (Figure SPM.3). Anthropogenic forcings have *likely* made a substantial contribution to surface temperature increases since the mid-20th century over every continental region except Antarctica[4]. Anthropogenic influences have *likely* affected the global water cycle since 1960 and contributed to the retreat of glaciers since the 1960s and to the increased surface melting of the Greenland ice sheet since 1993. Anthropogenic influences have *very likely* contributed to Arctic sea-ice loss since 1979 and have *very likely* made a substantial contribution to increases in global upper ocean heat content (0–700 m) and to global mean sea level rise observed since the 1970s. *{1.3, Figure 1.10}*

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[3] Greenhouse gas emissions are quantified as CO_2-equivalent ($GtCO_2$-eq) emissions using weightings based on the 100-year Global Warming Potentials, using IPCC Second Assessment Report values unless otherwise stated. *{Box 3.2}*

[4] For Antarctica, large observational uncertainties result in *low confidence* that anthropogenic forcings have contributed to the observed warming averaged over available stations.

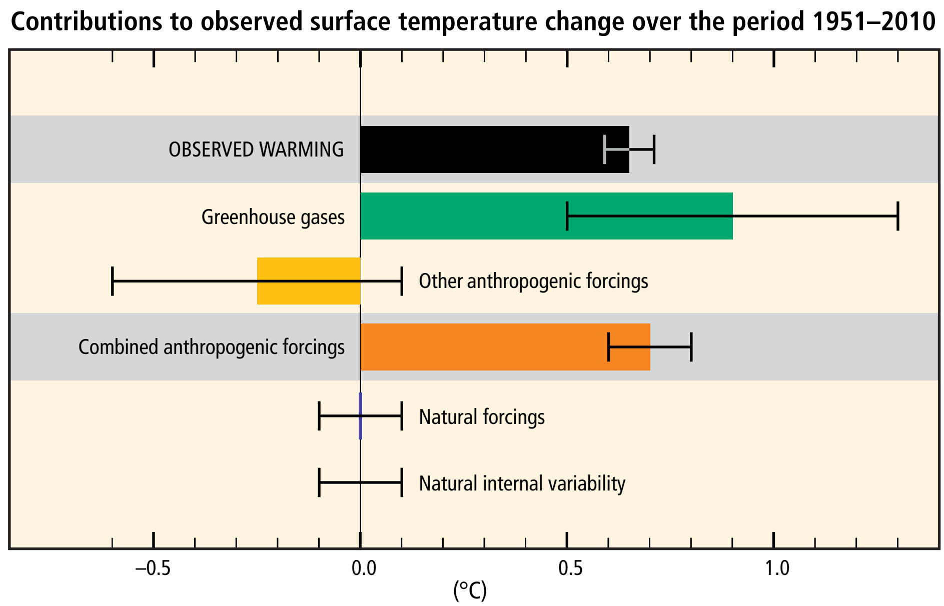

Figure SPM.3 | Assessed *likely* ranges (whiskers) and their mid-points (bars) for warming trends over the 1951–2010 period from well-mixed greenhouse gases, other anthropogenic forcings (including the cooling effect of aerosols and the effect of land use change), combined anthropogenic forcings, natural forcings and natural internal climate variability (which is the element of climate variability that arises spontaneously within the climate system even in the absence of forcings). The observed surface temperature change is shown in black, with the 5 to 95% uncertainty range due to observational uncertainty. The attributed warming ranges (colours) are based on observations combined with climate model simulations, in order to estimate the contribution of an individual external forcing to the observed warming. The contribution from the combined anthropogenic forcings can be estimated with less uncertainty than the contributions from greenhouse gases and from other anthropogenic forcings separately. This is because these two contributions partially compensate, resulting in a combined signal that is better constrained by observations. *{Figure 1.9}*

SPM 1.3 Impacts of climate change

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate. *{1.3.2}*

Evidence of observed climate change impacts is strongest and most comprehensive for natural systems. In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality (*medium confidence*). Many terrestrial, freshwater and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances and species interactions in response to ongoing climate change (*high confidence*). Some impacts on human systems have also been attributed to climate change, with a major or minor contribution of climate change distinguishable from other influences (Figure SPM.4). Assessment of many studies covering a wide range of regions and crops shows that negative impacts of climate change on crop yields have been more common than positive impacts (*high confidence*). Some impacts of ocean acidification on marine organisms have been attributed to human influence (*medium confidence*). *{1.3.2}*

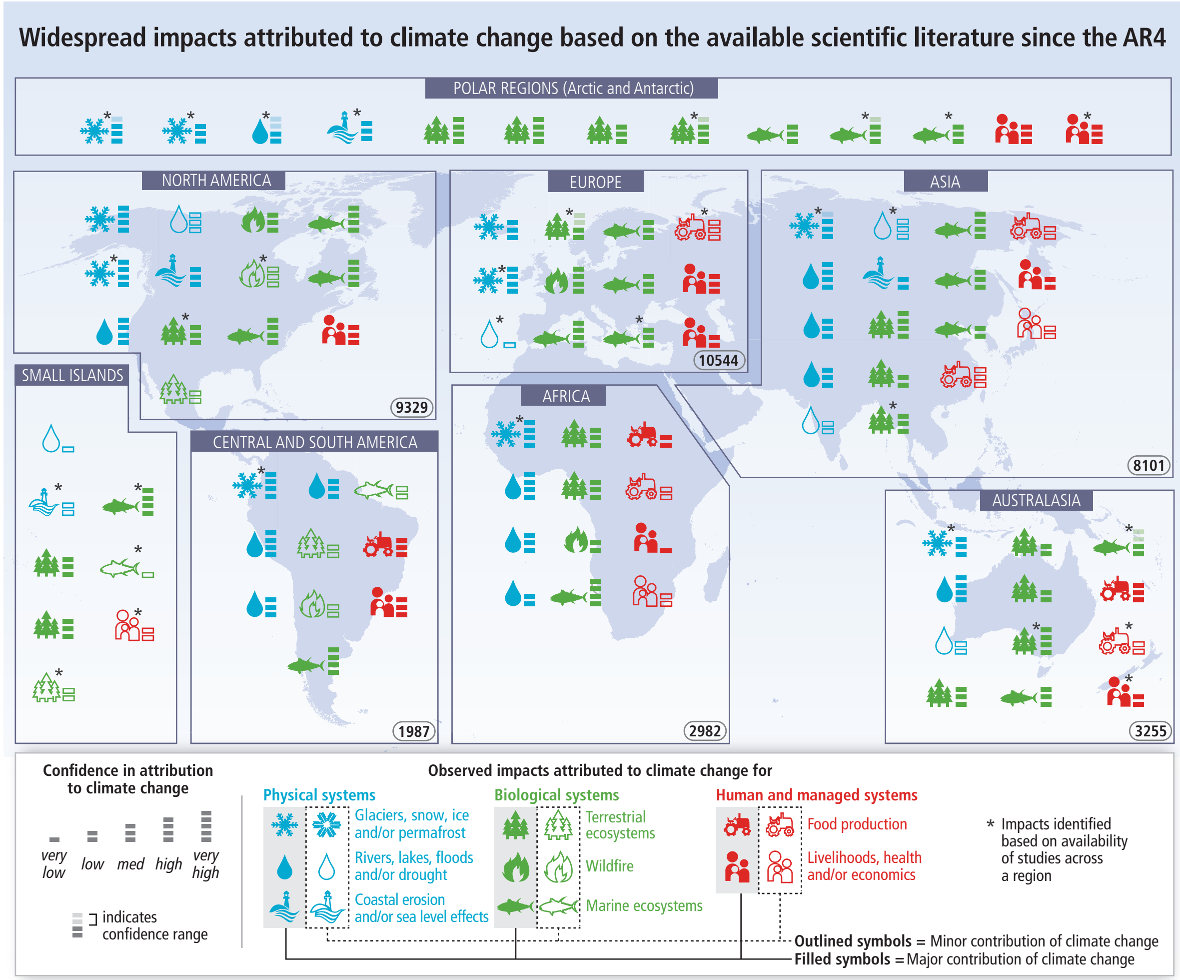

Figure SPM.4 | Based on the available scientific literature since the IPCC Fourth Assessment Report (AR4), there are substantially more impacts in recent decades now attributed to climate change. Attribution requires defined scientific evidence on the role of climate change. Absence from the map of additional impacts attributed to climate change does not imply that such impacts have not occurred. The publications supporting attributed impacts reflect a growing knowledge base, but publications are still limited for many regions, systems and processes, highlighting gaps in data and studies. Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact and confidence in attribution. Each symbol refers to one or more entries in WGII Table SPM.A1, grouping related regional-scale impacts. Numbers in ovals indicate regional totals of climate change publications from 2001 to 2010, based on the Scopus bibliographic database for publications in English with individual countries mentioned in title, abstract or key words (as of July 2011). These numbers provide an overall measure of the available scientific literature on climate change across regions; they do not indicate the number of publications supporting attribution of climate change impacts in each region. Studies for polar regions and small islands are grouped with neighbouring continental regions. The inclusion of publications for assessment of attribution followed IPCC scientific evidence criteria defined in WGII Chapter 18. Publications considered in the attribution analyses come from a broader range of literature assessed in the WGII AR5. See WGII Table SPM.A1 for descriptions of the attributed impacts. *{Figure 1.11}*

SPM 1.4 Extreme events

Changes in many extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events in a number of regions. *{1.4}*

It is *very likely* that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is *likely* that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. It is

very likely that human influence has contributed to the observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century. It is *likely* that human influence has more than doubled the probability of occurrence of heat waves in some locations. There is *medium confidence* that the observed warming has increased heat-related human mortality and decreased cold-related human mortality in some regions. *{1.4}*

There are *likely* more land regions where the number of heavy precipitation events has increased than where it has decreased. Recent detection of increasing trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at regional scale (*medium confidence*). It is *likely* that extreme sea levels (for example, as experienced in storm surges) have increased since 1970, being mainly a result of rising mean sea level. *{1.4}*

Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability (*very high confidence*). *{1.4}*

SPM 2. Future Climate Changes, Risks and Impacts

Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks. *{2}*

SPM 2.1 Key drivers of future climate

Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. Projections of greenhouse gas emissions vary over a wide range, depending on both socio-economic development and climate policy. *{2.1}*

Anthropogenic GHG emissions are mainly driven by population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy. The Representative Concentration Pathways (RCPs), which are used for making projections based on these factors, describe four different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). Scenarios without additional efforts to constrain emissions ('baseline scenarios') lead to pathways ranging between RCP6.0 and RCP8.5 (Figure SPM.5a). RCP2.6 is representative of a scenario that aims to keep global warming *likely* below 2°C above pre-industrial temperatures. The RCPs are consistent with the wide range of scenarios in the literature as assessed by WGIII[5]. *{2.1, Box 2.2, 4.3}*

Multiple lines of evidence indicate a strong, consistent, almost linear relationship between cumulative CO_2 emissions and projected global temperature change to the year 2100 in both the RCPs and the wider set of mitigation scenarios analysed in WGIII (Figure SPM.5b). Any given level of warming is associated with a range of cumulative CO_2 emissions[6], and therefore, e.g., higher emissions in earlier decades imply lower emissions later. *{2.2.5, Table 2.2}*

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[5] Roughly 300 baseline scenarios and 900 mitigation scenarios are categorized by CO_2-equivalent concentration (CO_2-eq) by 2100. The CO_2-eq includes the forcing due to all GHGs (including halogenated gases and tropospheric ozone), aerosols and albedo change.

[6] Quantification of this range of CO_2 emissions requires taking into account non-CO_2 drivers.

SPM

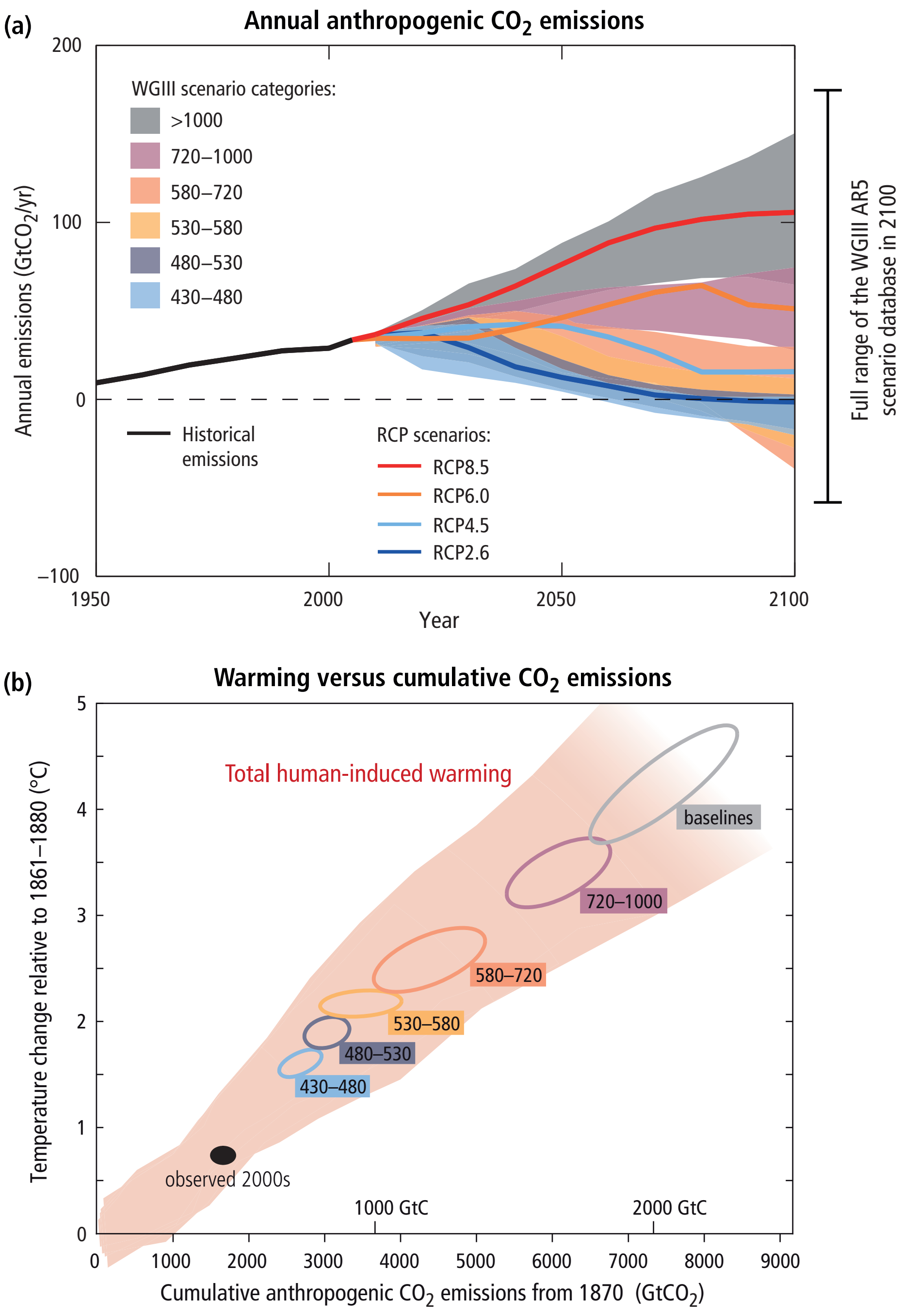

Figure SPM.5 | **(a)** Emissions of carbon dioxide (CO_2) alone in the Representative Concentration Pathways (RCPs) (lines) and the associated scenario categories used in WGIII (coloured areas show 5 to 95% range). The WGIII scenario categories summarize the wide range of emission scenarios published in the scientific literature and are defined on the basis of CO_2-eq concentration levels (in ppm) in 2100. The time series of other greenhouse gas emissions are shown in Box 2.2, Figure 1. **(b)** Global mean surface temperature increase at the time global CO_2 emissions reach a given net cumulative total, plotted as a function of that total, from various lines of evidence. Coloured plume shows the spread of past and future projections from a hierarchy of climate-carbon cycle models driven by historical emissions and the four RCPs over all times out to 2100, and fades with the decreasing number of available models. Ellipses show total anthropogenic warming in 2100 versus cumulative CO_2 emissions from 1870 to 2100 from a simple climate model (median climate response) under the scenario categories used in WGIII. The width of the ellipses in terms of temperature is caused by the impact of different scenarios for non-CO_2 climate drivers. The filled black ellipse shows observed emissions to 2005 and observed temperatures in the decade 2000–2009 with associated uncertainties. *{Box 2.2, Figure 1; Figure 2.3}*

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Multi-model results show that limiting total human-induced warming to less than 2°C relative to the period 1861–1880 with a probability of >66%[7] would require cumulative CO_2 emissions from all anthropogenic sources since 1870 to remain below about 2900 $GtCO_2$ (with a range of 2550 to 3150 $GtCO_2$ depending on non-CO_2 drivers). About 1900 $GtCO_2$[8] had already been emitted by 2011. For additional context see Table 2.2. *{2.2.5}*

SPM 2.2 Projected changes in the climate system

Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is *very likely* that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise. *{2.2}*

The projected changes in Section SPM 2.2 are for 2081–2100 relative to 1986–2005, unless otherwise indicated.

Future climate will depend on committed warming caused by past anthropogenic emissions, as well as future anthropogenic emissions and natural climate variability. The global mean surface temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four RCPs and will *likely* be in the range 0.3°C to 0.7°C (*medium confidence*). This assumes that there will be no major volcanic eruptions or changes in some natural sources (e.g., CH_4 and N_2O), or unexpected changes in total solar irradiance. By mid-21st century, the magnitude of the projected climate change is substantially affected by the choice of emissions scenario. *{2.2.1, Table 2.1}*

Relative to 1850–1900, global surface temperature change for the end of the 21st century (2081–2100) is projected to *likely* exceed 1.5°C for RCP4.5, RCP6.0 and RCP8.5 (*high confidence*). Warming is *likely* to exceed 2°C for RCP6.0 and RCP8.5 (*high confidence*), *more likely than not* to exceed 2°C for RCP4.5 (*medium confidence*), but *unlikely* to exceed 2°C for RCP2.6 (*medium confidence*). *{2.2.1}*

The increase of global mean surface temperature by the end of the 21st century (2081–2100) relative to 1986–2005 is *likely* to be 0.3°C to 1.7°C under RCP2.6, 1.1°C to 2.6°C under RCP4.5, 1.4°C to 3.1°C under RCP6.0 and 2.6°C to 4.8°C under RCP8.5[9]. The Arctic region will continue to warm more rapidly than the global mean (Figure SPM.6a, Figure SPM.7a). *{2.2.1, Figure 2.1, Figure 2.2, Table 2.1}*

It is *virtually certain* that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases. It is *very likely* that heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur. *{2.2.1}*

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[7] Corresponding figures for limiting warming to 2°C with a probability of >50% and >33% are 3000 $GtCO_2$ (range of 2900 to 3200 $GtCO_2$) and 3300 $GtCO_2$ (range of 2950 to 3800 $GtCO_2$) respectively. Higher or lower temperature limits would imply larger or lower cumulative emissions respectively.

[8] This corresponds to about two thirds of the 2900 $GtCO_2$ that would limit warming to less than 2°C with a probability of >66%; to about 63% of the total amount of 3000 $GtCO_2$ that would limit warming to less than 2°C with a probability of >50%; and to about 58% of the total amount of 3300 $GtCO_2$ that would limit warming to less than 2°C with a probability of >33%.

[9] The period 1986–2005 is approximately 0.61 [0.55 to 0.67] °C warmer than 1850–1900. *{2.2.1}*

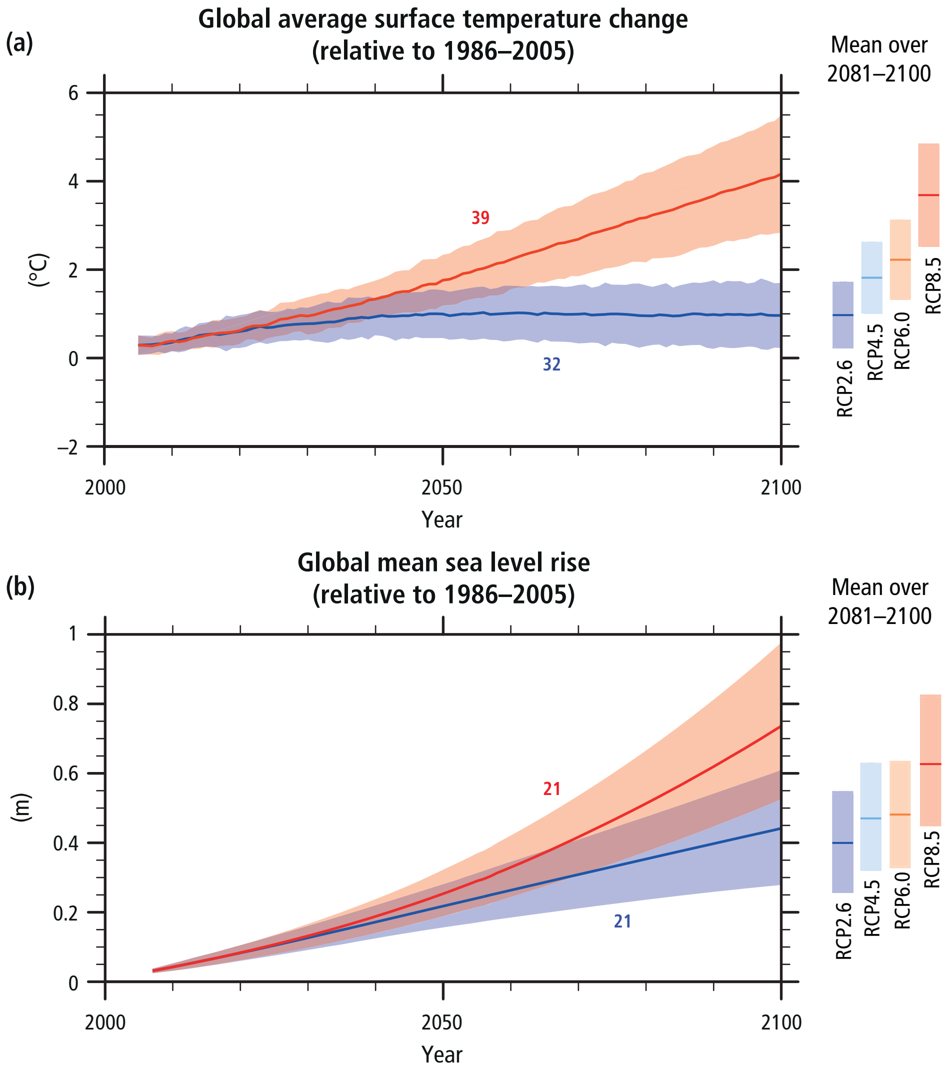

Figure SPM.6 | Global average surface temperature change **(a)** and global mean sea level rise[10] **(b)** from 2006 to 2100 as determined by multi-model simulations. All changes are relative to 1986–2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). The mean and associated uncertainties averaged over 2081–2100 are given for all RCP scenarios as coloured vertical bars at the right hand side of each panel. The number of Coupled Model Intercomparison Project Phase 5 (CMIP5) models used to calculate the multi-model mean is indicated. *{2.2, Figure 2.1}*

Changes in precipitation will not be uniform. The high latitudes and the equatorial Pacific are *likely* to experience an increase in annual mean precipitation under the RCP8.5 scenario. In many mid-latitude and subtropical dry regions, mean precipitation will *likely* decrease, while in many mid-latitude wet regions, mean precipitation will *likely* increase under the RCP8.5 scenario (Figure SPM.7b). Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will *very likely* become more intense and more frequent. *{2.2.2, Figure 2.2}*

The global ocean will continue to warm during the 21st century, with the strongest warming projected for the surface in tropical and Northern Hemisphere subtropical regions (Figure SPM.7a). *{2.2.3, Figure 2.2}*

[10] Based on current understanding (from observations, physical understanding and modelling), only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. There is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century.

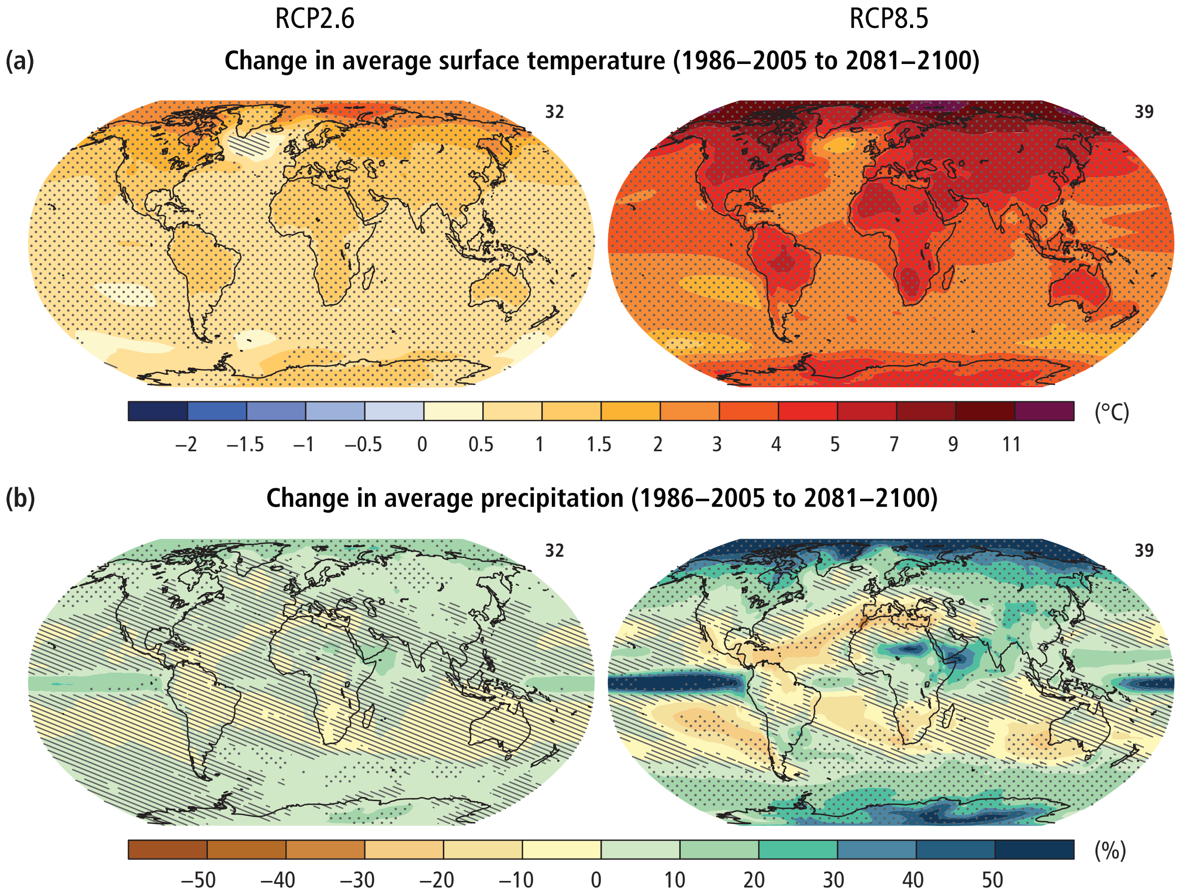

Figure SPM.7 | Change in average surface temperature **(a)** and change in average precipitation **(b)** based on multi-model mean projections for 2081–2100 relative to 1986–2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios. The number of models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Stippling (i.e., dots) shows regions where the projected change is large compared to natural internal variability and where at least 90% of models agree on the sign of change. Hatching (i.e., diagonal lines) shows regions where the projected change is less than one standard deviation of the natural internal variability. *{2.2, Figure 2.2}*

Earth System Models project a global increase in ocean acidification for all RCP scenarios by the end of the 21st century, with a slow recovery after mid-century under RCP2.6. The decrease in surface ocean pH is in the range of 0.06 to 0.07 (15 to 17% increase in acidity) for RCP2.6, 0.14 to 0.15 (38 to 41%) for RCP4.5, 0.20 to 0.21 (58 to 62%) for RCP6.0 and 0.30 to 0.32 (100 to 109%) for RCP8.5. *{2.2.4, Figure 2.1}*

Year-round reductions in Arctic sea ice are projected for all RCP scenarios. A nearly ice-free[11] Arctic Ocean in the summer sea-ice minimum in September before mid-century is *likely* for RCP8.5[12] (*medium confidence*). *{2.2.3, Figure 2.1}*

It is *virtually certain* that near-surface permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases, with the area of permafrost near the surface (upper 3.5 m) projected to decrease by 37% (RCP2.6) to 81% (RCP8.5) for the multi-model average (*medium confidence*). *{2.2.3}*

The global glacier volume, excluding glaciers on the periphery of Antarctica (and excluding the Greenland and Antarctic ice sheets), is projected to decrease by 15 to 55% for RCP2.6 and by 35 to 85% for RCP8.5 (*medium confidence*). *{2.2.3}*

[11] When sea-ice extent is less than one million km^2 for at least five consecutive years.

[12] Based on an assessment of the subset of models that most closely reproduce the climatological mean state and 1979–2012 trend of the Arctic sea-ice extent.

There has been significant improvement in understanding and projection of sea level change since the AR4. Global mean sea level rise will continue during the 21st century, *very likely* at a faster rate than observed from 1971 to 2010. For the period 2081–2100 relative to 1986–2005, the rise will *likely* be in the ranges of 0.26 to 0.55 m for RCP2.6, and of 0.45 to 0.82 m for RCP8.5 (*medium confidence*)[10] (Figure SPM.6b). Sea level rise will not be uniform across regions. By the end of the 21st century, it is *very likely* that sea level will rise in more than about 95% of the ocean area. About 70% of the coastlines worldwide are projected to experience a sea level change within ±20% of the global mean. *{2.2.3}*

SPM 2.3 Future risks and impacts caused by a changing climate

Climate change will amplify existing risks and create new risks for natural and human systems. Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development. *{2.3}*

Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems, including their ability to adapt. Rising rates and magnitudes of warming and other changes in the climate system, accompanied by ocean acidification, increase the risk of severe, pervasive and in some cases irreversible detrimental impacts. Some risks are particularly relevant for individual regions (Figure SPM.8), while others are global. The overall risks of future climate change impacts can be reduced by limiting the rate and magnitude of climate change, including ocean acidification. The precise levels of climate change sufficient to trigger abrupt and irreversible change remain uncertain, but the risk associated with crossing such thresholds increases with rising temperature (*medium confidence*). For risk assessment, it is important to evaluate the widest possible range of impacts, including low-probability outcomes with large consequences. *{1.5, 2.3, 2.4, 3.3, Box Introduction.1, Box 2.3, Box 2.4}*

A large fraction of species faces increased extinction risk due to climate change during and beyond the 21st century, especially as climate change interacts with other stressors (*high confidence*). Most plant species cannot naturally shift their geographical ranges sufficiently fast to keep up with current and high projected rates of climate change in most landscapes; most small mammals and freshwater molluscs will not be able to keep up at the rates projected under RCP4.5 and above in flat landscapes in this century (*high confidence*). Future risk is indicated to be high by the observation that natural global climate change at rates lower than current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years. Marine organisms will face progressively lower oxygen levels and high rates and magnitudes of ocean acidification (*high confidence*), with associated risks exacerbated by rising ocean temperature extremes (*medium confidence*). Coral reefs and polar ecosystems are highly vulnerable. Coastal systems and low-lying areas are at risk from sea level rise, which will continue for centuries even if the global mean temperature is stabilized (*high confidence*). *{2.3, 2.4, Figure 2.5}*

Climate change is projected to undermine food security (Figure SPM.9). Due to projected climate change by the mid-21st century and beyond, global marine species redistribution and marine biodiversity reduction in sensitive regions will challenge the sustained provision of fisheries productivity and other ecosystem services (*high confidence*). For wheat, rice and maize in tropical and temperate regions, climate change without adaptation is projected to negatively impact production for local temperature increases of 2°C or more above late 20th century levels, although individual locations may benefit (*medium confidence*). Global temperature increases of ~4°C or more[13] above late 20th century levels, combined with increasing food demand, would pose large risks to food security globally (*high confidence*). Climate change is projected to reduce renewable surface water and groundwater resources in most dry subtropical regions (*robust evidence*, *high agreement*), intensifying competition for water among sectors (*limited evidence*, *medium agreement*). *{2.3.1, 2.3.2}*

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[13] Projected warming averaged over land is larger than global average warming for all RCP scenarios for the period 2081–2100 relative to 1986–2005. For regional projections, see Figure SPM.7. *{2.2}*

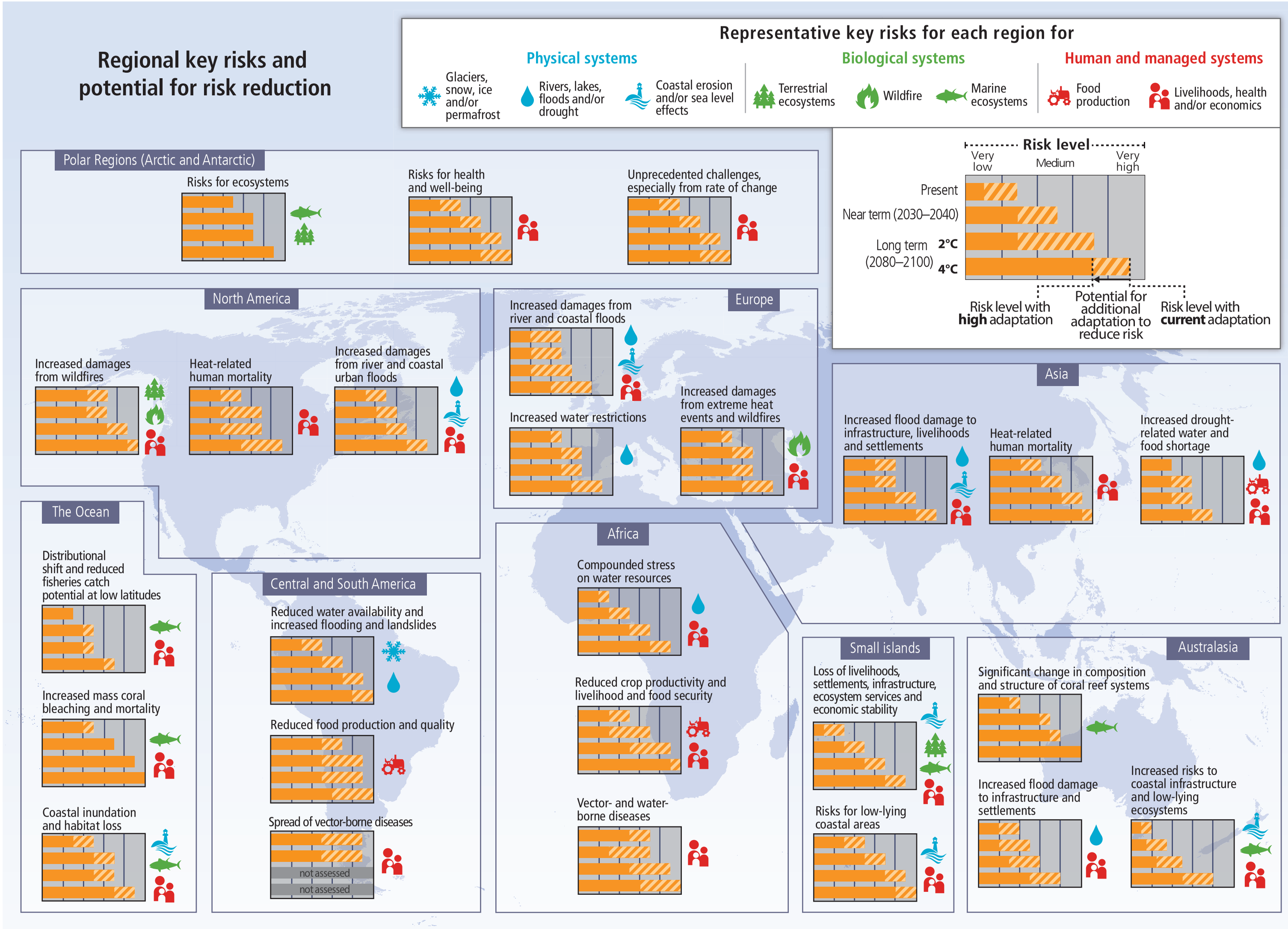

Figure SPM.8 | Representative key risks[14] for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation. Each key risk is assessed as very low, low, medium, high or very high. Risk levels are presented for three time frames: present, near term (here, for 2030–2040) and long term (here, for 2080–2100). In the near term, projected levels of global mean temperature increase do not diverge substantially across different emission scenarios. For the long term, risk levels are presented for two possible futures (2°C and 4°C global mean temperature increase above pre-industrial levels). For each timeframe, risk levels are indicated for a continuation of current adaptation and assuming high levels of current or future adaptation. Risk levels are not necessarily comparable, especially across regions. *{Figure 2.4}*

[14] Identification of key risks was based on expert judgment using the following specific criteria: large magnitude, high probability or irreversibility of impacts; timing of impacts; persistent vulnerability or exposure contributing to risks; or limited potential to reduce risks through adaptation or mitigation.

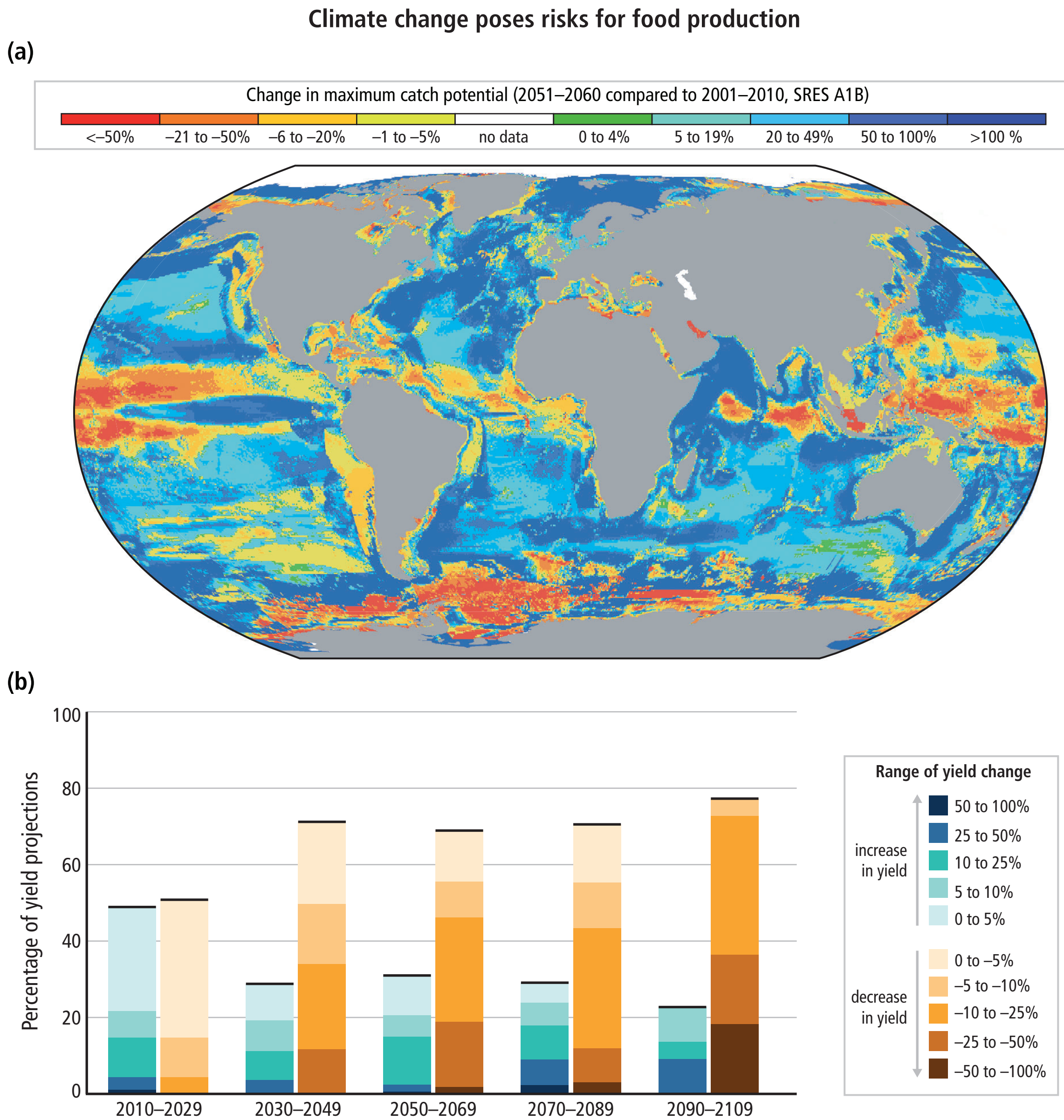

Figure SPM.9 | **(a)** Projected global redistribution of maximum catch potential of ~1000 exploited marine fish and invertebrate species. Projections compare the 10-year averages 2001–2010 and 2051–2060 using ocean conditions based on a single climate model under a moderate to high warming scenario, without analysis of potential impacts of overfishing or ocean acidification. **(b)** Summary of projected changes in crop yields (mostly wheat, maize, rice and soy), due to climate change over the 21st century. Data for each timeframe sum to 100%, indicating the percentage of projections showing yield increases versus decreases. The figure includes projections (based on 1090 data points) for different emission scenarios, for tropical and temperate regions and for adaptation and no-adaptation cases combined. Changes in crop yields are relative to late 20th century levels. *{Figure 2.6a, Figure 2.7}*

Until mid-century, projected climate change will impact human health mainly by exacerbating health problems that already exist (*very high confidence*). Throughout the 21st century, climate change is expected to lead to increases in ill-health in many regions and especially in developing countries with low income, as compared to a baseline without climate change (*high confidence*). By 2100 for RCP8.5, the combination of high temperature and humidity in some areas for parts of the year is expected to compromise common human activities, including growing food and working outdoors (*high confidence*). *{2.3.2}*

In urban areas climate change is projected to increase risks for people, assets, economies and ecosystems, including risks from heat stress, storms and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea level rise and storm surges (*very high confidence*). These risks are amplified for those lacking essential infrastructure and services or living in exposed areas. *{2.3.2}*

Rural areas are expected to experience major impacts on water availability and supply, food security, infrastructure and agricultural incomes, including shifts in the production areas of food and non-food crops around the world (*high confidence*). *{2.3.2}*

Aggregate economic losses accelerate with increasing temperature (*limited evidence, high agreement*), but global economic impacts from climate change are currently difficult to estimate. From a poverty perspective, climate change impacts are projected to slow down economic growth, make poverty reduction more difficult, further erode food security and prolong existing and create new poverty traps, the latter particularly in urban areas and emerging hotspots of hunger (*medium confidence*). International dimensions such as trade and relations among states are also important for understanding the risks of climate change at regional scales. *{2.3.2}*

Climate change is projected to increase displacement of people (*medium evidence, high agreement*). Populations that lack the resources for planned migration experience higher exposure to extreme weather events, particularly in developing countries with low income. Climate change can indirectly increase risks of violent conflicts by amplifying well-documented drivers of these conflicts such as poverty and economic shocks (*medium confidence*). *{2.3.2}*

SPM 2.4 Climate change beyond 2100, irreversibility and abrupt changes

Many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. The risks of abrupt or irreversible changes increase as the magnitude of the warming increases. *{2.4}*

Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions. A large fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial timescale, except in the case of a large net removal of CO_2 from the atmosphere over a sustained period. *{2.4, Figure 2.8}*

Stabilization of global average surface temperature does not imply stabilization for all aspects of the climate system. Shifting biomes, soil carbon, ice sheets, ocean temperatures and associated sea level rise all have their own intrinsic long timescales which will result in changes lasting hundreds to thousands of years after global surface temperature is stabilized. *{2.1, 2.4}*

There is *high confidence* that ocean acidification will increase for centuries if CO_2 emissions continue, and will strongly affect marine ecosystems. *{2.4}*

It is *virtually certain* that global mean sea level rise will continue for many centuries beyond 2100, with the amount of rise dependent on future emissions. The threshold for the loss of the Greenland ice sheet over a millennium or more, and an associated sea level rise of up to 7 m, is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) of global warming with respect to pre-industrial temperatures. Abrupt and irreversible ice loss from the Antarctic ice sheet is possible, but current evidence and understanding is insufficient to make a quantitative assessment. *{2.4}*

Magnitudes and rates of climate change associated with medium- to high-emission scenarios pose an increased risk of abrupt and irreversible regional-scale change in the composition, structure and function of marine, terrestrial and freshwater ecosystems, including wetlands (*medium confidence*). A reduction in permafrost extent is *virtually certain* with continued rise in global temperatures. *{2.4}*

SPM 3. Future Pathways for Adaptation, Mitigation and Sustainable Development

Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to climate-resilient pathways for sustainable development. *{3.2, 3.3, 3.4}*

SPM 3.1 Foundations of decision-making about climate change

Effective decision-making to limit climate change and its effects can be informed by a wide range of analytical approaches for evaluating expected risks and benefits, recognizing the importance of governance, ethical dimensions, equity, value judgments, economic assessments and diverse perceptions and responses to risk and uncertainty. *{3.1}*

Sustainable development and equity provide a basis for assessing climate policies. Limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication. Countries' past and future contributions to the accumulation of GHGs in the atmosphere are different, and countries also face varying challenges and circumstances and have different capacities to address mitigation and adaptation. Mitigation and adaptation raise issues of equity, justice and fairness. Many of those most vulnerable to climate change have contributed and contribute little to GHG emissions. Delaying mitigation shifts burdens from the present to the future, and insufficient adaptation responses to emerging impacts are already eroding the basis for sustainable development. Comprehensive strategies in response to climate change that are consistent with sustainable development take into account the co-benefits, adverse side effects and risks that may arise from both adaptation and mitigation options. *{3.1, 3.5, Box 3.4}*

The design of climate policy is influenced by how individuals and organizations perceive risks and uncertainties and take them into account. Methods of valuation from economic, social and ethical analysis are available to assist decision-making. These methods can take account of a wide range of possible impacts, including low-probability outcomes with large consequences. But they cannot identify a single best balance between mitigation, adaptation and residual climate impacts. *{3.1}*

Climate change has the characteristics of a collective action problem at the global scale, because most GHGs accumulate over time and mix globally, and emissions by any agent (e.g., individual, community, company, country) affect other agents. Effective mitigation will not be achieved if individual agents advance their own interests independently. Cooperative responses, including international cooperation, are therefore required to effectively mitigate GHG emissions and address other climate change issues. The effectiveness of adaptation can be enhanced through complementary actions across levels, including international cooperation. The evidence suggests that outcomes seen as equitable can lead to more effective cooperation. *{3.1}*

SPM 3.2 Climate change risks reduced by mitigation and adaptation

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*). Mitigation involves some level of co-benefits and of risks due to adverse side effects, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change, increasing the benefits from near-term mitigation efforts. *{3.2, 3.4}*

Mitigation and adaptation are complementary approaches for reducing risks of climate change impacts over different time-scales (*high confidence*). Mitigation, in the near term and through the century, can substantially reduce climate change

impacts in the latter decades of the 21st century and beyond. Benefits from adaptation can already be realized in addressing current risks, and can be realized in the future for addressing emerging risks. *{3.2, 4.5}*

Five Reasons For Concern (RFCs) aggregate climate change risks and illustrate the implications of warming and of adaptation limits for people, economies and ecosystems across sectors and regions. The five RFCs are associated with: (1) Unique and threatened systems, (2) Extreme weather events, (3) Distribution of impacts, (4) Global aggregate impacts, and (5) Large-scale singular events. In this report, the RFCs provide information relevant to Article 2 of UNFCCC. *{Box 2.4}*

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*) (Figure SPM.10). In most scenarios without additional mitigation efforts (those with 2100 atmospheric concentrations

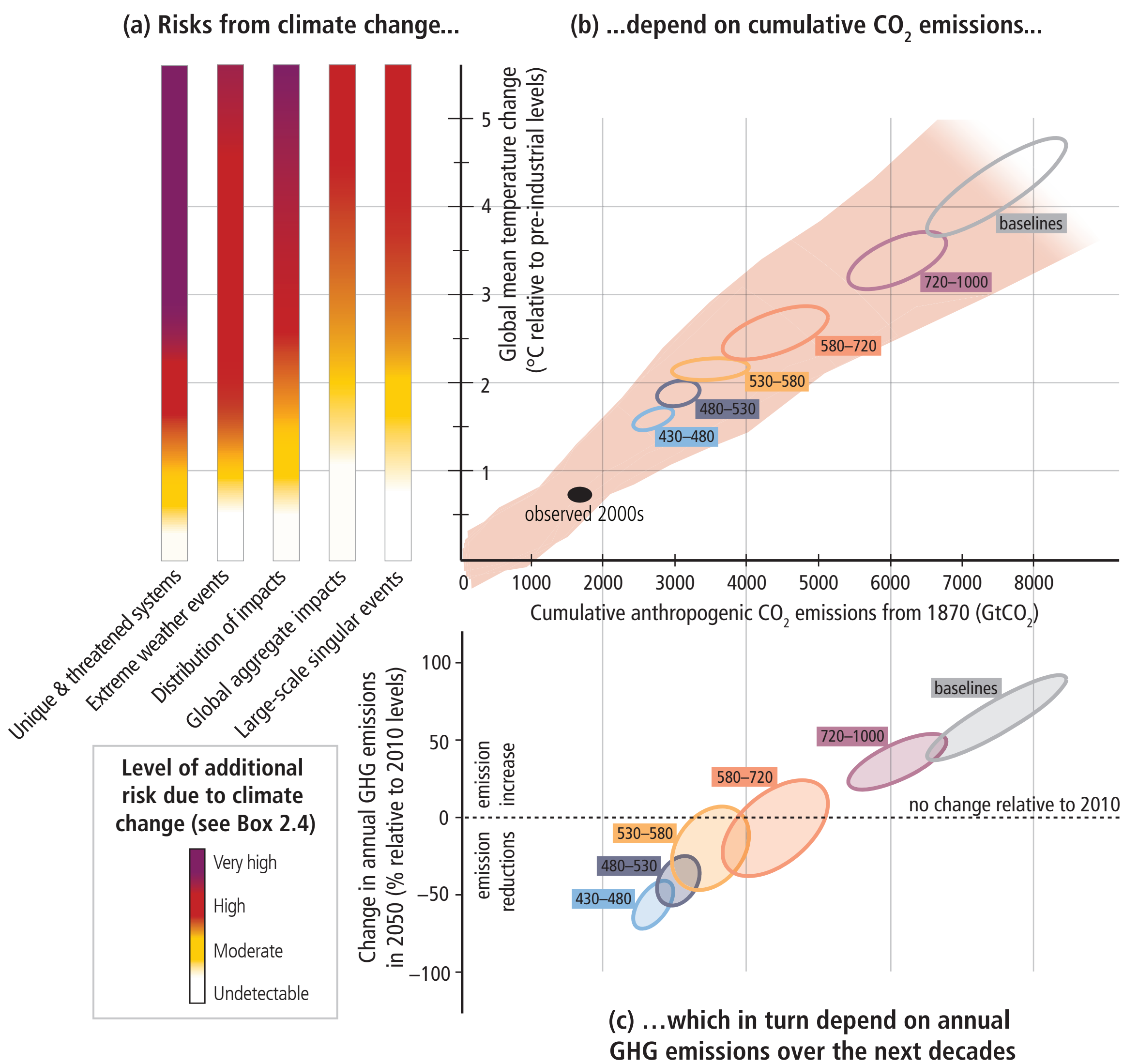

Figure SPM.10 | The relationship between risks from climate change, temperature change, cumulative carbon dioxide (CO_2) emissions and changes in annual greenhouse gas (GHG) emissions by 2050. Limiting risks across Reasons For Concern **(a)** would imply a limit for cumulative emissions of CO_2 **(b)** which would constrain annual GHG emissions over the next few decades **(c)**. **Panel a** reproduces the five Reasons For Concern *{Box 2.4}*. **Panel b** links temperature changes to cumulative CO_2 emissions (in $GtCO_2$) from 1870. They are based on Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations (pink plume) and on a simple climate model (median climate response in 2100), for the baselines and five mitigation scenario categories (six ellipses). Details are provided in Figure SPM.5. **Panel c** shows the relationship between the cumulative CO_2 emissions (in $GtCO_2$) of the scenario categories and their associated change in annual GHG emissions by 2050, expressed in percentage change (in percent $GtCO_2$-eq per year) relative to 2010. The ellipses correspond to the same scenario categories as in Panel b, and are built with a similar method (see details in Figure SPM.5). *{Figure 3.1}*

>1000 ppm CO_2-eq), warming is *more likely than not* to exceed 4°C above pre-industrial levels by 2100 (Table SPM.1). The risks associated with temperatures at or above 4°C include substantial species extinction, global and regional food insecurity, consequential constraints on common human activities and limited potential for adaptation in some cases (*high confidence*). Some risks of climate change, such as risks to unique and threatened systems and risks associated with extreme weather events, are moderate to high at temperatures 1°C to 2°C above pre-industrial levels. *{2.3, Figure 2.5, 3.2, 3.4, Box 2.4, Table SPM.1}*

Substantial cuts in GHG emissions over the next few decades can substantially reduce risks of climate change by limiting warming in the second half of the 21st century and beyond. Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. Limiting risks across RFCs would imply a limit for cumulative emissions of CO_2. Such a limit would require that global net emissions of CO_2 eventually decrease to zero and would constrain annual emissions over the next few decades (Figure SPM.10) (*high confidence*). But some risks from climate damages are unavoidable, even with mitigation and adaptation. *{2.2.5, 3.2, 3.4}*

Mitigation involves some level of co-benefits and risks, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change. Inertia in the economic and climate system and the possibility of irreversible impacts from climate change increase the benefits from near-term mitigation efforts (*high confidence*). Delays in additional mitigation or constraints on technological options increase the longer-term mitigation costs to hold climate change risks at a given level (Table SPM.2). *{3.2, 3.4}*

SPM 3.3 Characteristics of adaptation pathways

Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, especially with greater magnitudes and rates of climate change. Taking a longer-term perspective, in the context of sustainable development, increases the likelihood that more immediate adaptation actions will also enhance future options and preparedness. *{3.3}*

Adaptation can contribute to the well-being of populations, the security of assets and the maintenance of ecosystem goods, functions and services now and in the future. Adaptation is place- and context-specific (*high confidence*). A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability (*high confidence*). Integration of adaptation into planning, including policy design, and decision-making can promote synergies with development and disaster risk reduction. Building adaptive capacity is crucial for effective selection and implementation of adaptation options (*robust evidence, high agreement*). *{3.3}*

Adaptation planning and implementation can be enhanced through complementary actions across levels, from individuals to governments (*high confidence*). National governments can coordinate adaptation efforts of local and sub-national governments, for example by protecting vulnerable groups, by supporting economic diversification and by providing information, policy and legal frameworks and financial support (*robust evidence*, *high agreement*). Local government and the private sector are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing (*medium evidence*, *high agreement*). *{3.3}*

Adaptation planning and implementation at all levels of governance are contingent on societal values, objectives and risk perceptions (*high confidence*). Recognition of diverse interests, circumstances, social-cultural contexts and expectations can benefit decision-making processes. Indigenous, local and traditional knowledge systems and practices, including indigenous peoples' holistic view of community and environment, are a major resource for adapting to climate change, but these have not been used consistently in existing adaptation efforts. Integrating such forms of knowledge with existing practices increases the effectiveness of adaptation. *{3.3}*

Constraints can interact to impede adaptation planning and implementation (*high confidence*). Common constraints on implementation arise from the following: limited financial and human resources; limited integration or coordination of governance; uncertainties about projected impacts; different perceptions of risks; competing values; absence of key adaptation leaders and advocates; and limited tools to monitor adaptation effectiveness. Another constraint includes insufficient research, monitoring, and observation and the finance to maintain them. *{3.3}*

Greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*). Limits to adaptation emerge from the interaction among climate change and biophysical and/or socio-economic constraints. Further, poor planning or implementation, overemphasizing short-term outcomes or failing to sufficiently anticipate consequences can result in maladaptation, increasing the vulnerability or exposure of the target group in the future or the vulnerability of other people, places or sectors (*medium evidence, high agreement*). Underestimating the complexity of adaptation as a social process can create unrealistic expectations about achieving intended adaptation outcomes. *{3.3}*

Significant co-benefits, synergies and trade-offs exist between mitigation and adaptation and among different adaptation responses; interactions occur both within and across regions (*very high confidence*). Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, particularly at the intersections among water, energy, land use and biodiversity, but tools to understand and manage these interactions remain limited. Examples of actions with co-benefits include (i) improved energy efficiency and cleaner energy sources, leading to reduced emissions of health-damaging, climate-altering air pollutants; (ii) reduced energy and water consumption in urban areas through greening cities and recycling water; (iii) sustainable agriculture and forestry; and (iv) protection of ecosystems for carbon storage and other ecosystem services. *{3.3}*

Transformations in economic, social, technological and political decisions and actions can enhance adaptation and promote sustainable development (*high confidence*). At the national level, transformation is considered most effective when it reflects a country's own visions and approaches to achieving sustainable development in accordance with its national circumstances and priorities. Restricting adaptation responses to incremental changes to existing systems and structures, without considering transformational change, may increase costs and losses and miss opportunities. Planning and implementation of transformational adaptation could reflect strengthened, altered or aligned paradigms and may place new and increased demands on governance structures to reconcile different goals and visions for the future and to address possible equity and ethical implications. Adaptation pathways are enhanced by iterative learning, deliberative processes and innovation. *{3.3}*

SPM 3.4 Characteristics of mitigation pathways

There are multiple mitigation pathways that are *likely* to limit warming to below 2°C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of CO_2 and other long-lived greenhouse gases by the end of the century. Implementing such reductions poses substantial technological, economic, social and institutional challenges, which increase with delays in additional mitigation and if key technologies are not available. Limiting warming to lower or higher levels involves similar challenges but on different timescales. *{3.4}*

Without additional efforts to reduce GHG emissions beyond those in place today, global emissions growth is expected to persist, driven by growth in global population and economic activities. Global mean surface temperature increases in 2100 in baseline scenarios—those without additional mitigation—range from 3.7°C to 4.8°C above the average for 1850–1900 for a median climate response. They range from 2.5°C to 7.8°C when including climate uncertainty (5th to 95th percentile range) (*high confidence*). *{3.4}*

Emissions scenarios leading to CO_2-equivalent concentrations in 2100 of about 450 ppm or lower are *likely* to maintain warming below 2°C over the 21st century relative to pre-industrial levels[15]. These scenarios are characterized by 40 to 70% global anthropogenic GHG emissions reductions by 2050 compared to 2010[16], and emissions levels near zero or below in 2100. Mitigation scenarios reaching concentration levels of about 500 ppm CO_2-eq by 2100 are *more likely than not* to limit temperature change to less than 2°C, unless they temporarily overshoot concentration levels of roughly 530 ppm CO_2-eq

[15] For comparison, the CO_2-eq concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 to 520 ppm)

[16] This range differs from the range provided for a similar concentration category in the AR4 (50 to 85% lower than 2000 for CO_2 only). Reasons for this difference include that this report has assessed a substantially larger number of scenarios than in the AR4 and looks at all GHGs. In addition, a large proportion of the new scenarios include Carbon Dioxide Removal (CDR) technologies (see below). Other factors include the use of 2100 concentration levels instead of stabilization levels and the shift in reference year from 2000 to 2010.

before 2100, in which case they are *about as likely as not* to achieve that goal. In these 500 ppm CO_2-eq scenarios, global 2050 emissions levels are 25 to 55% lower than in 2010. Scenarios with higher emissions in 2050 are characterized by a greater reliance on Carbon Dioxide Removal (CDR) technologies beyond mid-century (and vice versa). Trajectories that are *likely* to limit warming to 3°C relative to pre-industrial levels reduce emissions less rapidly than those limiting warming to 2°C. A limited number of studies provide scenarios that are *more likely than not* to limit warming to 1.5°C by 2100; these scenarios are characterized by concentrations below 430 ppm CO_2-eq by 2100 and 2050 emission reduction between 70% and 95% below 2010. For a comprehensive overview of the characteristics of emissions scenarios, their CO_2-equivalent concentrations and their likelihood to keep warming to below a range of temperature levels, see Figure SPM.11 and Table SPM.1. *{3.4}*

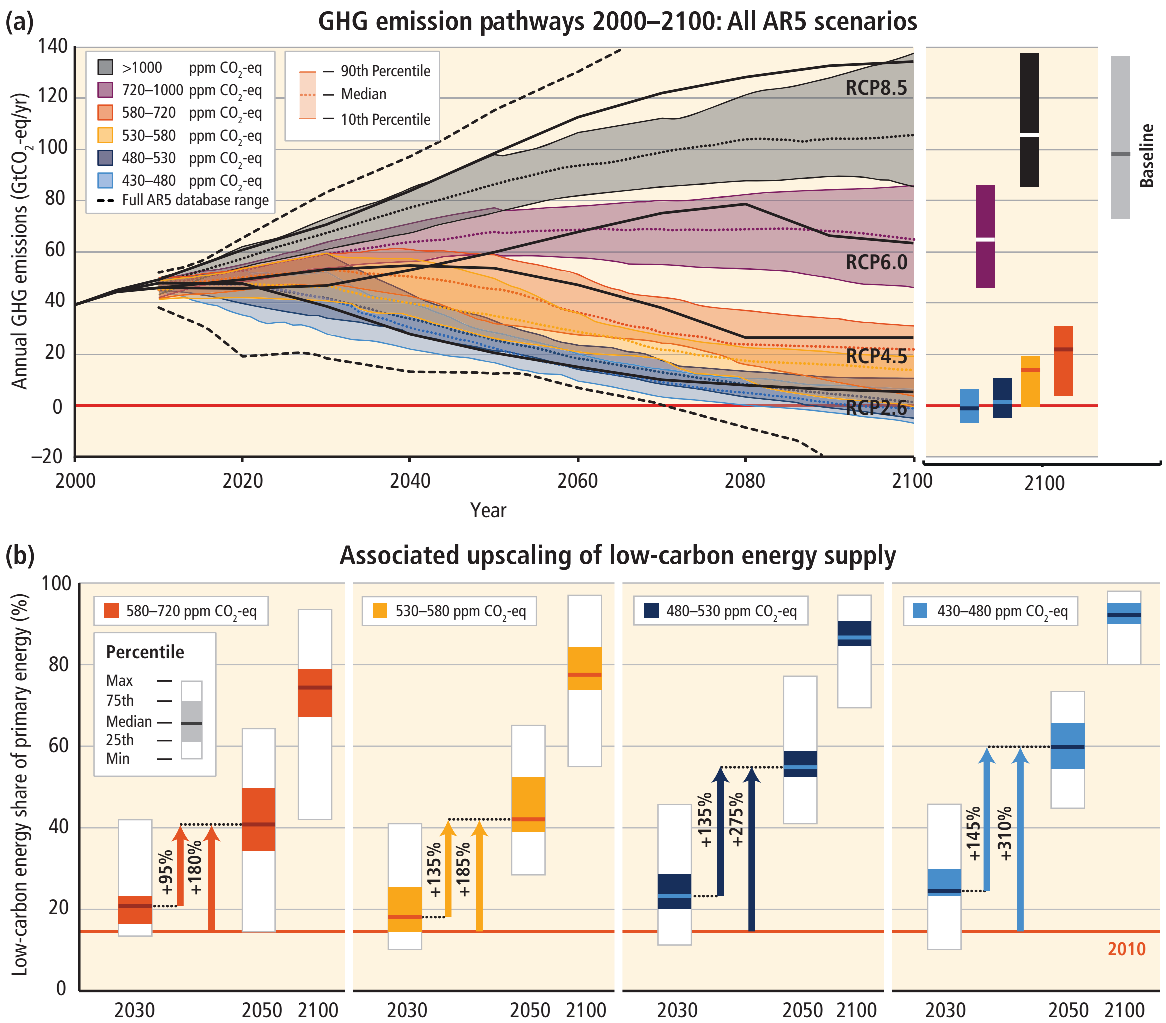

Figure SPM.11 | Global greenhouse gas emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) in baseline and mitigation scenarios for different long-term concentration levels **(a)** and associated upscaling requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100 compared to 2010 levels in mitigation scenarios **(b)**. *{Figure 3.2}*

SPM

Table SPM.1 | Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters the 10th to 90th percentile of the scenarios is shown [a]. *{Table 3.1}*

<table>
<tr><th rowspan="2">CO_2-eq Concentrations in 2100 (ppm CO_2-eq) [f]

Category label (conc. range)</th><th rowspan="2">Subcategories</th><th rowspan="2">Relative position of the RCPs [d]</th><th colspan="2">Change in CO_2-eq emissions compared to 2010 (in %) [c]</th><th colspan="4">Likelihood of staying below a specific temperature level over the 21st century (relative to 1850–1900) [d, e]</th></tr>
<tr><th>2050</th><th>2100</th><th>1.5°C</th><th>2°C</th><th>3°C</th><th>4°C</th></tr>
<tr><td><430</td><td colspan="8">Only a limited number of individual model studies have explored levels below 430 ppm CO_2-eq [j]</td></tr>
<tr><td>450
(430 to 480)</td><td>Total range [a, g]</td><td>RCP2.6</td><td>−72 to −41</td><td>−118 to −78</td><td>More unlikely than likely</td><td>Likely</td><td rowspan="6">Likely</td><td rowspan="8">Likely</td></tr>
<tr><td rowspan="2">500
(480 to 530)</td><td>No overshoot of 530 ppm CO_2-eq</td><td></td><td>−57 to −42</td><td>−107 to −73</td><td rowspan="6">Unlikely</td><td>More likely than not</td></tr>
<tr><td>Overshoot of 530 ppm CO_2-eq</td><td></td><td>−55 to −25</td><td>−114 to −90</td><td>About as likely as not</td></tr>
<tr><td rowspan="2">550
(530 to 580)</td><td>No overshoot of 580 ppm CO_2-eq</td><td></td><td>−47 to −19</td><td>−81 to −59</td><td rowspan="3">More unlikely than likely [i]</td></tr>
<tr><td>Overshoot of 580 ppm CO_2-eq</td><td></td><td>−16 to 7</td><td>−183 to −86</td></tr>
<tr><td>(580 to 650)</td><td>Total range</td><td rowspan="2">RCP4.5</td><td>−38 to 24</td><td>−134 to −50</td></tr>
<tr><td>(650 to 720)</td><td>Total range</td><td>−11 to 17</td><td>−54 to −21</td><td rowspan="2">Unlikely</td><td>More likely than not</td></tr>
<tr><td>(720 to 1000) [b]</td><td>Total range</td><td>RCP6.0</td><td>18 to 54</td><td>−7 to 72</td><td rowspan="2">Unlikely [h]</td><td>More unlikely than likely</td></tr>
<tr><td>>1000 [b]</td><td>Total range</td><td>RCP8.5</td><td>52 to 95</td><td>74 to 178</td><td>Unlikely [h]</td><td>Unlikely</td><td>More unlikely than likely</td></tr>
</table>

Notes:

[a] The 'total range' for the 430 to 480 ppm CO_2-eq concentrations scenarios corresponds to the range of the 10th to 90th percentile of the subcategory of these scenarios shown in Table 6.3 of the Working Group III Report.

[b] Baseline scenarios fall into the >1000 and 720 to 1000 ppm CO_2-eq categories. The latter category also includes mitigation scenarios. The baseline scenarios in the latter category reach a temperature change of 2.5°C to 5.8°C above the average for 1850–1900 in 2100. Together with the baseline scenarios in the >1000 ppm CO_2-eq category, this leads to an overall 2100 temperature range of 2.5°C to 7.8°C (range based on median climate response: 3.7°C to 4.8°C) for baseline scenarios across both concentration categories.

[c] The global 2010 emissions are 31% above the 1990 emissions (consistent with the historic greenhouse gas emission estimates presented in this report). CO_2-eq emissions include the basket of Kyoto gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) as well as fluorinated gases).

[d] The assessment here involves a large number of scenarios published in the scientific literature and is thus not limited to the Representative Concentration Pathways (RCPs). To evaluate the CO_2-eq concentration and climate implications of these scenarios, the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) was used in a probabilistic mode. For a comparison between MAGICC model results and the outcomes of the models used in WGI, see WGI 12.4.1.2, 12.4.8 and WGIII 6.3.2.6.

[e] The assessment in this table is based on the probabilities calculated for the full ensemble of scenarios in WGIII AR5 using MAGICC and the assessment in WGI of the uncertainty of the temperature projections not covered by climate models. The statements are therefore consistent with the statements in WGI, which are based on the Coupled Model Intercomparison Project Phase 5 (CMIP5) runs of the RCPs and the assessed uncertainties. Hence, the likelihood statements reflect different lines of evidence from both WGs. This WGI method was also applied for scenarios with intermediate concentration levels where no CMIP5 runs are available. The likelihood statements are indicative only *{WGIII 6.3}* and follow broadly the terms used by the WGI SPM for temperature projections: likely 66–100%, more likely than not >50–100%, about as likely as not 33–66%, and unlikely 0–33%. In addition the term more unlikely than likely 0–<50% is used.

[f] The CO_2-equivalent concentration (see Glossary) is calculated on the basis of the total forcing from a simple carbon cycle/climate model, MAGICC. The CO_2-equivalent concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 to 520 ppm). This is based on the assessment of total anthropogenic radiative forcing for 2011 relative to 1750 in WGI, i.e., 2.3 W/m^2, uncertainty range 1.1 to 3.3 W/m^2.

[g] The vast majority of scenarios in this category overshoot the category boundary of 480 ppm CO_2-eq concentration.

[h] For scenarios in this category, no CMIP5 run or MAGICC realization stays below the respective temperature level. Still, an *unlikely* assignment is given to reflect uncertainties that may not be reflected by the current climate models.

[i] Scenarios in the 580 to 650 ppm CO_2-eq category include both overshoot scenarios and scenarios that do not exceed the concentration level at the high end of the category (e.g., RCP4.5). The latter type of scenarios, in general, have an assessed probability of *more unlikely than likely* to stay below the 2°C temperature level, while the former are mostly assessed to have an *unlikely* probability of staying below this level.

[j] In these scenarios, global CO_2-eq emissions in 2050 are between 70 to 95% below 2010 emissions, and they are between 110 to 120% below 2010 emissions in 2100.

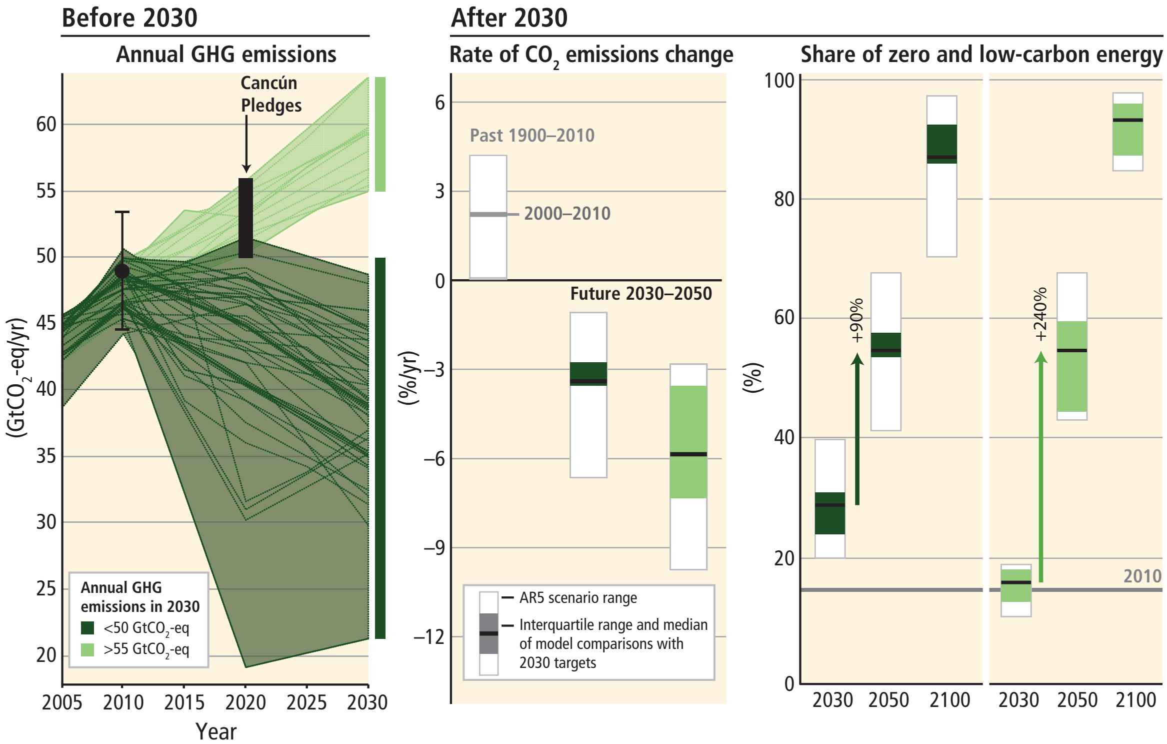

Figure SPM.12 | The implications of different 2030 greenhouse gas (GHG) emissions levels for the rate of carbon dioxide (CO_2) emissions reductions and low-carbon energy upscaling in mitigation scenarios that are at least *about as likely as not* to keep warming throughout the 21st century below 2°C relative to pre-industrial levels (2100 CO_2-equivalent concentrations of 430 to 530 ppm). The scenarios are grouped according to different emissions levels by 2030 (coloured in different shades of green). The left panel shows the pathways of GHG emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) leading to these 2030 levels. The black dot with whiskers gives historic GHG emission levels and associated uncertainties in 2010 as reported in Figure SPM.2. The black bar shows the estimated uncertainty range of GHG emissions implied by the Cancún Pledges. The middle panel denotes the average annual CO_2 emissions reduction rates for the period 2030–2050. It compares the median and interquartile range across scenarios from recent inter-model comparisons with explicit 2030 interim goals to the range of scenarios in the Scenario Database for WGIII AR5. Annual rates of historical emissions change (sustained over a period of 20 years) and the average annual CO_2 emission change between 2000 and 2010 are shown as well. The arrows in the right panel show the magnitude of zero and low-carbon energy supply upscaling from 2030 to 2050 subject to different 2030 GHG emissions levels. Zero- and low-carbon energy supply includes renewables, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS) or bioenergy with CCS (BECCS). [Note: Only scenarios that apply the full, unconstrained mitigation technology portfolio of the underlying models (default technology assumption) are shown. Scenarios with large net negative global emissions (>20 $GtCO_2$-eq/yr), scenarios with exogenous carbon price assumptions and scenarios with 2010 emissions significantly outside the historical range are excluded.] *{Figure 3.3}*

Mitigation scenarios reaching about 450 ppm CO_2-eq in 2100 (consistent with a *likely* chance to keep warming below 2°C relative to pre-industrial levels) typically involve temporary overshoot[17] of atmospheric concentrations, as do many scenarios reaching about 500 ppm CO_2-eq to about 550 ppm CO_2-eq in 2100 (Table SPM.1). Depending on the level of overshoot, overshoot scenarios typically rely on the availability and widespread deployment of bioenergy with carbon dioxide capture and storage (BECCS) and afforestation in the second half of the century. The availability and scale of these and other CDR technologies and methods are uncertain and CDR technologies are, to varying degrees, associated with challenges and risks[18]. CDR is also prevalent in many scenarios without overshoot to compensate for residual emissions from sectors where mitigation is more expensive (*high confidence*). *{3.4, Box 3.3}*

Reducing emissions of non-CO_2 agents can be an important element of mitigation strategies. All current GHG emissions and other forcing agents affect the rate and magnitude of climate change over the next few decades, although long-term warming is mainly driven by CO_2 emissions. Emissions of non-CO_2 forcers are often expressed as 'CO_2-equivalent emissions', but the choice of metric to calculate these emissions, and the implications for the emphasis and timing of abatement of the various climate forcers, depends on application and policy context and contains value judgments. *{3.4, Box 3.2}*

[17] In concentration 'overshoot' scenarios, concentrations peak during the century and then decline.

[18] CDR methods have biogeochemical and technological limitations to their potential on the global scale. There is insufficient knowledge to quantify how much CO_2 emissions could be partially offset by CDR on a century timescale. CDR methods may carry side effects and long-term consequences on a global scale.

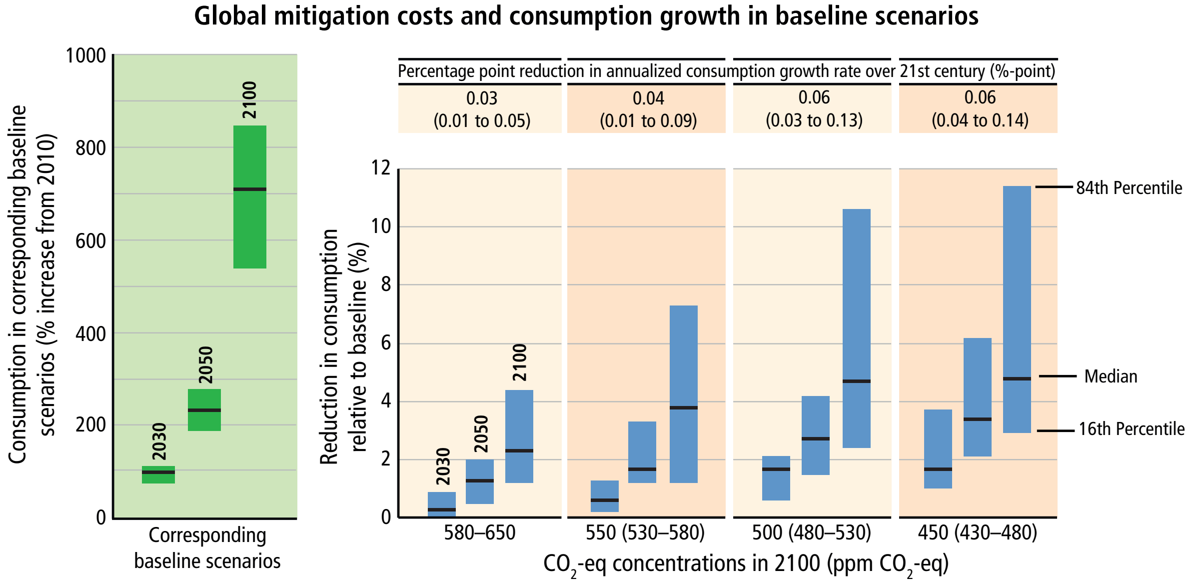

Figure SPM.13 | Global mitigation costs in cost-effective scenarios at different atmospheric concentrations levels in 2100. Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions. Consumption losses are shown relative to a baseline development without climate policy (left panel). The table at the top shows percentage points of annualized consumption growth reductions relative to consumption growth in the baseline of 1.6 to 3% per year (e.g., if the reduction is 0.06 percentage points per year due to mitigation, and baseline growth is 2.0% per year, then the growth rate with mitigation would be 1.94% per year). Cost estimates shown in this table do not consider the benefits of reduced climate change or co-benefits and adverse side effects of mitigation. Estimates at the high end of these cost ranges are from models that are relatively inflexible to achieve the deep emissions reductions required in the long run to meet these goals and/or include assumptions about market imperfections that would raise costs. *{Figure 3.4}*

Delaying additional mitigation to 2030 will substantially increase the challenges associated with limiting warming over the 21st century to below 2°C relative to pre-industrial levels. It will require substantially higher rates of emissions reductions from 2030 to 2050; a much more rapid scale-up of low-carbon energy over this period; a larger reliance on CDR in the long term; and higher transitional and long-term economic impacts. Estimated global emissions levels in 2020 based on the Cancún Pledges are not consistent with cost-effective mitigation trajectories that are at least *about as likely as not* to limit warming to below 2°C relative to pre-industrial levels, but they do not preclude the option to meet this goal (*high confidence*) (Figure SPM.12, Table SPM.2). *{3.4}*

Estimates of the aggregate economic costs of mitigation vary widely depending on methodologies and assumptions, but increase with the stringency of mitigation. Scenarios in which all countries of the world begin mitigation immediately, in which there is a single global carbon price, and in which all key technologies are available have been used as a cost-effective benchmark for estimating macro-economic mitigation costs (Figure SPM.13). Under these assumptions mitigation scenarios that are *likely* to limit warming to below 2°C through the 21st century relative to pre-industrial levels entail losses in global consumption—not including benefits of reduced climate change as well as co-benefits and adverse side effects of mitigation—of 1 to 4% (median: 1.7%) in 2030, 2 to 6% (median: 3.4%) in 2050 and 3 to 11% (median: 4.8%) in 2100 relative to consumption in baseline scenarios that grows anywhere from 300% to more than 900% over the century (Figure SPM.13). These numbers correspond to an annualized reduction of consumption growth by 0.04 to 0.14 (median: 0.06) percentage points over the century relative to annualized consumption growth in the baseline that is between 1.6 and 3% per year (*high confidence*). *{3.4}*

In the absence or under limited availability of mitigation technologies (such as bioenergy, CCS and their combination BECCS, nuclear, wind/solar), mitigation costs can increase substantially depending on the technology considered. Delaying additional mitigation increases mitigation costs in the medium to long term. Many models could not limit *likely* warming to below 2°C over the 21st century relative to pre-industrial levels if additional mitigation is considerably delayed. Many models could not limit *likely* warming to below 2°C if bioenergy, CCS and their combination (BECCS) are limited (*high confidence*) (Table SPM.2). *{3.4}*

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Table SPM.2 | Increase in global mitigation costs due to either limited availability of specific technologies or delays in additional mitigation [a] relative to cost-effective scenarios [b]. The increase in costs is given for the median estimate and the 16th to 84th percentile range of the scenarios (in parentheses) [c]. In addition, the sample size of each scenario set is provided in the coloured symbols. The colours of the symbols indicate the fraction of models from systematic model comparison exercises that could successfully reach the targeted concentration level. *{Table 3.2}*

	Mitigation cost increases in scenarios with limited availability of technologies [d] *[% increase in total discounted [e] mitigation costs (2015–2100) relative to default technology assumptions]*				Mitigation cost increases due to delayed additional mitigation until 2030 *[% increase in mitigation costs relative to immediate mitigation]*	
2100 concentrations (ppm CO_2-eq)	no CCS	nuclear phase out	limited solar/wind	limited bioenergy	medium term costs (2030–2050)	long term costs (2050–2100)
450 (430 to 480)	138% (29 to 297%) 4	7% (4 to 18%) 8	6% (2 to 29%) 8	64% (44 to 78%) 8	44% (2 to 78%) 29	37% (16 to 82%) 29
500 (480 to 530)	not available (n.a.)	n.a.	n.a.	n.a.		
550 (530 to 580)	39% (18 to 78%) 11	13% (2 to 23%) 10	8% (5 to 15%) 10	18% (4 to 66%) 12	15% (3 to 32%)	16% (5 to 24%)
580 to 650	n.a.	n.a.	n.a.	n.a.		

Symbol legend—fraction of models successful in producing scenarios (numbers indicate the number of successful models)

- Green: all models successful
- Tan: between 80 and 100% of models successful
- Orange: between 50 and 80% of models successful
- Pink: less than 50% of models successful

Notes:

[a] Delayed mitigation scenarios are associated with greenhouse gas emission of more than 55 $GtCO_2$-eq in 2030, and the increase in mitigation costs is measured relative to cost-effective mitigation scenarios for the same long-term concentration level.

[b] Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions.

[c] The range is determined by the central scenarios encompassing the 16th to 84th percentile range of the scenario set. Only scenarios with a time horizon until 2100 are included. Some models that are included in the cost ranges for concentration levels above 530 ppm CO_2-eq in 2100 could not produce associated scenarios for concentration levels below 530 ppm CO_2-eq in 2100 with assumptions about limited availability of technologies and/or delayed additional mitigation.

[d] No CCS: carbon dioxide capture and storage is not included in these scenarios. Nuclear phase out: no addition of nuclear power plants beyond those under construction, and operation of existing plants until the end of their lifetime. Limited Solar/Wind: a maximum of 20% global electricity generation from solar and wind power in any year of these scenarios. Limited Bioenergy: a maximum of 100 EJ/yr modern bioenergy supply globally (modern bioenergy used for heat, power, combinations and industry was around 18 EJ/yr in 2008). EJ = Exajoule = 10^{18} Joule.

[e] Percentage increase of net present value of consumption losses in percent of baseline consumption (for scenarios from general equilibrium models) and abatement costs in percent of baseline gross domestic product (GDP, for scenarios from partial equilibrium models) for the period 2015–2100, discounted at 5% per year.

Mitigation scenarios reaching about 450 or 500 ppm CO_2-eq by 2100 show reduced costs for achieving air quality and energy security objectives, with significant co-benefits for human health, ecosystem impacts and sufficiency of resources and resilience of the energy system. *{4.4.2.2}*

Mitigation policy could devalue fossil fuel assets and reduce revenues for fossil fuel exporters, but differences between regions and fuels exist (*high confidence*). Most mitigation scenarios are associated with reduced revenues from coal and oil trade for major exporters (*high confidence*). The availability of CCS would reduce the adverse effects of mitigation on the value of fossil fuel assets (*medium confidence*). *{4.4.2.2}*

Solar Radiation Management (SRM) involves large-scale methods that seek to reduce the amount of absorbed solar energy in the climate system. SRM is untested and is not included in any of the mitigation scenarios. If it were deployed, SRM would

entail numerous uncertainties, side effects, risks and shortcomings and has particular governance and ethical implications. SRM would not reduce ocean acidification. If it were terminated, there is *high confidence* that surface temperatures would rise very rapidly impacting ecosystems susceptible to rapid rates of change. *{Box 3.3}*

SPM 4. Adaptation and Mitigation

Many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives. *{4}*

SPM 4.1 Common enabling factors and constraints for adaptation and mitigation responses

Adaptation and mitigation responses are underpinned by common enabling factors. These include effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods and behavioural and lifestyle choices. *{4.1}*

Inertia in many aspects of the socio-economic system constrains adaptation and mitigation options (*medium evidence, high agreement*). Innovation and investments in environmentally sound infrastructure and technologies can reduce GHG emissions and enhance resilience to climate change (*very high confidence*). *{4.1}*

Vulnerability to climate change, GHG emissions and the capacity for adaptation and mitigation are strongly influenced by livelihoods, lifestyles, behaviour and culture (*medium evidence, medium agreement*). Also, the social acceptability and/or effectiveness of climate policies are influenced by the extent to which they incentivize or depend on regionally appropriate changes in lifestyles or behaviours. *{4.1}*

For many regions and sectors, enhanced capacities to mitigate and adapt are part of the foundation essential for managing climate change risks (*high confidence*). Improving institutions as well as coordination and cooperation in governance can help overcome regional constraints associated with mitigation, adaptation and disaster risk reduction (*very high confidence*). *{4.1}*

SPM 4.2 Response options for adaptation

Adaptation options exist in all sectors, but their context for implementation and potential to reduce climate-related risks differs across sectors and regions. Some adaptation responses involve significant co-benefits, synergies and trade-offs. Increasing climate change will increase challenges for many adaptation options. *{4.2}*

Adaptation experience is accumulating across regions in the public and private sectors and within communities. There is increasing recognition of the value of social (including local and indigenous), institutional, and ecosystem-based measures and of the extent of constraints to adaptation. Adaptation is becoming embedded in some planning processes, with more limited implementation of responses (*high confidence*). *{1.6, 4.2, 4.4.2.1}*

The need for adaptation along with associated challenges is expected to increase with climate change (*very high confidence*). Adaptation options exist in all sectors and regions, with diverse potential and approaches depending on their context in vulnerability reduction, disaster risk management or proactive adaptation planning (Table SPM.3). Effective strategies and actions consider the potential for co-benefits and opportunities within wider strategic goals and development plans. *{4.2}*

Table SPM.3 | Approaches for managing the risks of climate change through adaptation. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Examples are presented in no specific order and can be relevant to more than one category. *{Table 4.2}*

Overlapping Approaches	Category	Examples
Vulnerability & Exposure Reduction through development, planning & practices including many low-regrets measures	Human development	Improved access to education, nutrition, health facilities, energy, safe housing & settlement structures, & social support structures; Reduced gender inequality & marginalization in other forms.
	Poverty alleviation	Improved access to & control of local resources; Land tenure; Disaster risk reduction; Social safety nets & social protection; Insurance schemes.
	Livelihood security	Income, asset & livelihood diversification; Improved infrastructure; Access to technology & decision-making fora; Increased decision-making power; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
	Disaster risk management	Early warning systems; Hazard & vulnerability mapping; Diversifying water resources; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements.
	Ecosystem management	Maintaining wetlands & urban green spaces; Coastal afforestation; Watershed & reservoir management; Reduction of other stressors on ecosystems & of habitat fragmentation; Maintenance of genetic diversity; Manipulation of disturbance regimes; Community-based natural resource management.
	Spatial or land-use planning	Provisioning of adequate housing, infrastructure & services; Managing development in flood prone & other high risk areas; Urban planning & upgrading programs; Land zoning laws; Easements; Protected areas.
Adaptation including incremental & transformational adjustments	Structural/physical	***Engineered & built-environment options***: Sea walls & coastal protection structures; Flood levees; Water storage; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements; Floating houses; Power plant & electricity grid adjustments.
		Technological options: New crop & animal varieties; Indigenous, traditional & local knowledge, technologies & methods; Efficient irrigation; Water-saving technologies; Desalinisation; Conservation agriculture; Food storage & preservation facilities; Hazard & vulnerability mapping & monitoring; Early warning systems; Building insulation; Mechanical & passive cooling; Technology development, transfer & diffusion.
		Ecosystem-based options: Ecological restoration; Soil conservation; Afforestation & reforestation; Mangrove conservation & replanting; Green infrastructure (e.g., shade trees, green roofs); Controlling overfishing; Fisheries co-management; Assisted species migration & dispersal; Ecological corridors; Seed banks, gene banks & other *ex situ* conservation; Community-based natural resource management.
		Services: Social safety nets & social protection; Food banks & distribution of food surplus; Municipal services including water & sanitation; Vaccination programs; Essential public health services; Enhanced emergency medical services.
	Institutional	***Economic options***: Financial incentives; Insurance; Catastrophe bonds; Payments for ecosystem services; Pricing water to encourage universal provision and careful use; Microfinance; Disaster contingency funds; Cash transfers; Public-private partnerships.
		Laws & regulations: Land zoning laws; Building standards & practices; Easements; Water regulations & agreements; Laws to support disaster risk reduction; Laws to encourage insurance purchasing; Defined property rights & land tenure security; Protected areas; Fishing quotas; Patent pools & technology transfer.
		National & government policies & programs: National & regional adaptation plans including mainstreaming; Sub-national & local adaptation plans; Economic diversification; Urban upgrading programs; Municipal water management programs; Disaster planning & preparedness; Integrated water resource management; Integrated coastal zone management; Ecosystem-based management; Community-based adaptation.
	Social	***Educational options***: Awareness raising & integrating into education; Gender equity in education; Extension services; Sharing indigenous, traditional & local knowledge; Participatory action research & social learning; Knowledge-sharing & learning platforms.
		Informational options: Hazard & vulnerability mapping; Early warning & response systems; Systematic monitoring & remote sensing; Climate services; Use of indigenous climate observations; Participatory scenario development; Integrated assessments.
		Behavioural options: Household preparation & evacuation planning; Migration; Soil & water conservation; Storm drain clearance; Livelihood diversification; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
Transformation	Spheres of change	***Practical***: Social & technical innovations, behavioural shifts, or institutional & managerial changes that produce substantial shifts in outcomes.
		Political: Political, social, cultural & ecological decisions & actions consistent with reducing vulnerability & risk & supporting adaptation, mitigation & sustainable development.
		Personal: Individual & collective assumptions, beliefs, values & worldviews influencing climate-change responses.

SPM 4.3 Response options for mitigation

Mitigation options are available in every major sector. Mitigation can be more cost-effective if using an integrated approach that combines measures to reduce energy use and the greenhouse gas intensity of end-use sectors, decarbonize energy supply, reduce net emissions and enhance carbon sinks in land-based sectors. *{4.3}*

Well-designed systemic and cross-sectoral mitigation strategies are more cost-effective in cutting emissions than a focus on individual technologies and sectors, with efforts in one sector affecting the need for mitigation in others (*medium confidence*). Mitigation measures intersect with other societal goals, creating the possibility of co-benefits or adverse side effects. These intersections, if well-managed, can strengthen the basis for undertaking climate action. *{4.3}*

Emissions ranges for baseline scenarios and mitigation scenarios that limit CO_2-equivalent concentrations to low levels (about 450 ppm CO_2-eq, *likely* to limit warming to 2°C above pre-industrial levels) are shown for different sectors and gases in Figure SPM.14. Key measures to achieve such mitigation goals include decarbonizing (i.e., reducing the carbon intensity of) electricity generation (*medium evidence, high agreement*) as well as efficiency enhancements and behavioural changes, in order to reduce energy demand compared to baseline scenarios without compromising development (*robust evidence, high agreement*). In scenarios reaching 450 ppm CO_2-eq concentrations by 2100, global CO_2 emissions from the energy supply sector are projected to decline over the next decade and are characterized by reductions of 90% or more below 2010 levels between 2040 and 2070. In the majority of low-concentration stabilization scenarios (about 450 to about 500 ppm CO_2-eq, at least *about as likely as not* to limit warming to 2°C above pre-industrial levels), the share of low-carbon electricity supply (comprising renewable energy (RE), nuclear and carbon dioxide capture and storage (CCS) including bioenergy with carbon dioxide capture and storage (BECCS)) increases from the current share of approximately 30% to more than 80% by 2050, and fossil fuel power generation without CCS is phased out almost entirely by 2100. *{4.3}*

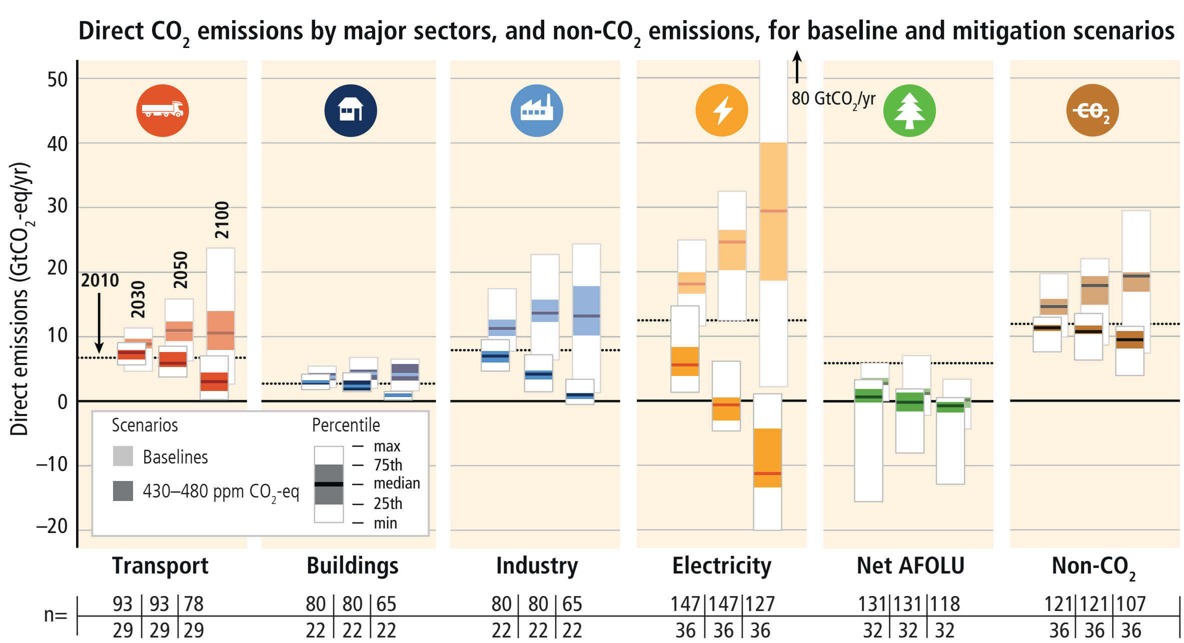

Figure SPM.14 | Carbon dioxide (CO_2) emissions by sector and total non-CO_2 greenhouse gases (Kyoto gases) across sectors in baseline (faded bars) and mitigation scenarios (solid colour bars) that reach about 450 (430 to 480) ppm CO_2-eq concentrations in 2100 (*likely* to limit warming to 2°C above pre-industrial levels). Mitigation in the end-use sectors leads also to indirect emissions reductions in the upstream energy supply sector. Direct emissions of the end-use sectors thus do not include the emission reduction potential at the supply-side due to, for example, reduced electricity demand. The numbers at the bottom of the graphs refer to the number of scenarios included in the range (upper row: baseline scenarios; lower row: mitigation scenarios), which differs across sectors and time due to different sectoral resolution and time horizon of models. Emissions ranges for mitigation scenarios include the full portfolio of mitigation options; many models cannot reach 450 ppm CO_2-eq concentration by 2100 in the absence of carbon dioxide capture and storage (CCS). Negative emissions in the electricity sector are due to the application of bioenergy with carbon dioxide capture and storage (BECCS). 'Net' agriculture, forestry and other land use (AFOLU) emissions consider afforestation, reforestation as well as deforestation activities. *{4.3, Figure 4.1}*

Near-term reductions in energy demand are an important element of cost-effective mitigation strategies, provide more flexibility for reducing carbon intensity in the energy supply sector, hedge against related supply-side risks, avoid lock-in to carbon-intensive infrastructures, and are associated with important co-benefits. The most cost-effective mitigation options in forestry are afforestation, sustainable forest management and reducing deforestation, with large differences in their relative importance across regions; and in agriculture, cropland management, grazing land management and restoration of organic soils (*medium evidence, high agreement*). *{4.3, Figures 4.1, 4.2, Table 4.3}*

Behaviour, lifestyle and culture have a considerable influence on energy use and associated emissions, with high mitigation potential in some sectors, in particular when complementing technological and structural change (*medium evidence, medium agreement*). Emissions can be substantially lowered through changes in consumption patterns, adoption of energy savings measures, dietary change and reduction in food wastes. *{4.1, 4.3}*

SPM 4.4 Policy approaches for adaptation and mitigation, technology and finance

Effective adaptation and mitigation responses will depend on policies and measures across multiple scales: international, regional, national and sub-national. Policies across all scales supporting technology development, diffusion and transfer, as well as finance for responses to climate change, can complement and enhance the effectiveness of policies that directly promote adaptation and mitigation. *{4.4}*

International cooperation is critical for effective mitigation, even though mitigation can also have local co-benefits. Adaptation focuses primarily on local to national scale outcomes, but its effectiveness can be enhanced through coordination across governance scales, including international cooperation: *{3.1, 4.4.1}*

- The United Nations Framework Convention on Climate Change (UNFCCC) is the main multilateral forum focused on addressing climate change, with nearly universal participation. Other institutions organized at different levels of governance have resulted in diversifying international climate change cooperation. *{4.4.1}*

- The Kyoto Protocol offers lessons towards achieving the ultimate objective of the UNFCCC, particularly with respect to participation, implementation, flexibility mechanisms and environmental effectiveness (*medium evidence, low agreement*). *{4.4.1}*

- Policy linkages among regional, national and sub-national climate policies offer potential climate change mitigation benefits (*medium evidence, medium agreement*). Potential advantages include lower mitigation costs, decreased emission leakage and increased market liquidity. *{4.4.1}*

- International cooperation for supporting adaptation planning and implementation has received less attention historically than mitigation but is increasing and has assisted in the creation of adaptation strategies, plans and actions at the national, sub-national and local level (*high confidence*). *{4.4.1}*

There has been a considerable increase in national and sub-national plans and strategies on both adaptation and mitigation since the AR4, with an increased focus on policies designed to integrate multiple objectives, increase co-benefits and reduce adverse side effects (*high confidence*): *{4.4.2.1, 4.4.2.2}*

- National governments play key roles in adaptation planning and implementation (*robust evidence, high agreement*) through coordinating actions and providing frameworks and support. While local government and the private sector have different functions, which vary regionally, they are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing (*medium evidence, high agreement*). *{4.4.2.1}*

- Institutional dimensions of adaptation governance, including the integration of adaptation into planning and decision-making, play a key role in promoting the transition from planning to implementation of adaptation (*robust evidence,*

high agreement). Examples of institutional approaches to adaptation involving multiple actors include economic options (e.g., insurance, public-private partnerships), laws and regulations (e.g., land-zoning laws) and national and government policies and programmes (e.g., economic diversification). *{4.2, 4.4.2.1, Table SPM.3}*

- In principle, mechanisms that set a carbon price, including cap and trade systems and carbon taxes, can achieve mitigation in a cost-effective way but have been implemented with diverse effects due in part to national circumstances as well as policy design. The short-run effects of cap and trade systems have been limited as a result of loose caps or caps that have not proved to be constraining (*limited evidence, medium agreement*). In some countries, tax-based policies specifically aimed at reducing GHG emissions—alongside technology and other policies—have helped to weaken the link between GHG emissions and GDP (*high confidence*). In addition, in a large group of countries, fuel taxes (although not necessarily designed for the purpose of mitigation) have had effects that are akin to sectoral carbon taxes. *{4.4.2.2}*

- Regulatory approaches and information measures are widely used and are often environmentally effective (*medium evidence, medium agreement*). Examples of regulatory approaches include energy efficiency standards; examples of information programmes include labelling programmes that can help consumers make better-informed decisions. *{4.4.2.2}*

- Sector-specific mitigation policies have been more widely used than economy-wide policies (*medium evidence, high agreement*). Sector-specific policies may be better suited to address sector-specific barriers or market failures and may be bundled in packages of complementary policies. Although theoretically more cost-effective, administrative and political barriers may make economy-wide policies harder to implement. Interactions between or among mitigation policies may be synergistic or may have no additive effect on reducing emissions. *{4.4.2.2}*

- Economic instruments in the form of subsidies may be applied across sectors, and include a variety of policy designs, such as tax rebates or exemptions, grants, loans and credit lines. An increasing number and variety of renewable energy (RE) policies including subsidies—motivated by many factors—have driven escalated growth of RE technologies in recent years. At the same time, reducing subsidies for GHG-related activities in various sectors can achieve emission reductions, depending on the social and economic context (*high confidence*). *{4.4.2.2}*

Co-benefits and adverse side effects of mitigation could affect achievement of other objectives such as those related to human health, food security, biodiversity, local environmental quality, energy access, livelihoods and equitable sustainable development. The potential for co-benefits for energy end-use measures outweighs the potential for adverse side effects whereas the evidence suggests this may not be the case for all energy supply and agriculture, forestry and other land use (AFOLU) measures. Some mitigation policies raise the prices for some energy services and could hamper the ability of societies to expand access to modern energy services to underserved populations (*low confidence*). These potential adverse side effects on energy access can be avoided with the adoption of complementary policies such as income tax rebates or other benefit transfer mechanisms (*medium confidence*). Whether or not side effects materialize, and to what extent side effects materialize, will be case- and site-specific, and depend on local circumstances and the scale, scope and pace of implementation. Many co-benefits and adverse side effects have not been well-quantified. *{4.3, 4.4.2.2, Box 3.4}*

Technology policy (development, diffusion and transfer) complements other mitigation policies across all scales, from international to sub-national; many adaptation efforts also critically rely on diffusion and transfer of technologies and management practices (*high confidence*). Policies exist to address market failures in R&D, but the effective use of technologies can also depend on capacities to adopt technologies appropriate to local circumstances. *{4.4.3}*

Substantial reductions in emissions would require large changes in investment patterns (*high confidence*). For mitigation scenarios that stabilize concentrations (without overshoot) in the range of 430 to 530 ppm CO_2-eq by 2100[19], annual investments in low carbon electricity supply and energy efficiency in key sectors (transport, industry and buildings) are projected in the scenarios to rise by several hundred billion dollars per year before 2030. Within appropriate enabling environments, the private sector, along with the public sector, can play important roles in financing mitigation and adaptation (*medium evidence, high agreement*). *{4.4.4}*

[19] This range comprises scenarios that reach 430 to 480 ppm CO_2-eq by 2100 (*likely* to limit warming to 2°C above pre-industrial levels) and scenarios that reach 480 to 530 ppm CO_2-eq by 2100 (without overshoot: *more likely than* not to limit warming to 2°C above pre-industrial levels).

Financial resources for adaptation have become available more slowly than for mitigation in both developed and developing countries. Limited evidence indicates that there is a gap between global adaptation needs and the funds available for adaptation (*medium confidence*). There is a need for better assessment of global adaptation costs, funding and investment. Potential synergies between international finance for disaster risk management and adaptation have not yet been fully realized (*high confidence*). *{4.4.4}*

SPM 4.5 Trade-offs, synergies and interactions with sustainable development

Climate change is a threat to sustainable development. Nonetheless, there are many opportunities to link mitigation, adaptation and the pursuit of other societal objectives through integrated responses (*high confidence*). Successful implementation relies on relevant tools, suitable governance structures and enhanced capacity to respond (*medium confidence*). *{3.5, 4.5}*

Climate change exacerbates other threats to social and natural systems, placing additional burdens particularly on the poor (*high confidence*). Aligning climate policy with sustainable development requires attention to both adaptation and mitigation (*high confidence*). Delaying global mitigation actions may reduce options for climate-resilient pathways and adaptation in the future. Opportunities to take advantage of positive synergies between adaptation and mitigation may decrease with time, particularly if limits to adaptation are exceeded. Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, encompassing connections among human health, water, energy, land use and biodiversity (*medium evidence, high agreement*). *{3.1, 3.5, 4.5}*

Strategies and actions can be pursued now which will move towards climate-resilient pathways for sustainable development, while at the same time helping to improve livelihoods, social and economic well-being and effective environmental management. In some cases, economic diversification can be an important element of such strategies. The effectiveness of integrated responses can be enhanced by relevant tools, suitable governance structures and adequate institutional and human capacity (*medium confidence*). Integrated responses are especially relevant to energy planning and implementation; interactions among water, food, energy and biological carbon sequestration; and urban planning, which provides substantial opportunities for enhanced resilience, reduced emissions and more sustainable development (*medium confidence*). *{3.5, 4.4, 4.5}*

Global Energy Review: CO_2 Emissions in 2020

Understanding the impacts of Covid-19 on global CO_2 emissions

Report
02 March 2021

The Covid-19 pandemic resulted in the largest-ever decline in global emissions

The Covid-19 pandemic and resulting economic crisis had an impact on almost every aspect of how energy is produced, supplied, and consumed around the world. The pandemic defined energy and emissions trends in 2020 – it drove down fossil fuel consumption for much of the year, whereas renewables and electric vehicles, two of the main building blocks of clean energy transitions, were largely immune.

As primary energy demand dropped nearly 4% in 2020, global energy-related CO_2 emissions fell by 5.8% according to the latest statistical data, the largest annual percentage decline since World War II. In absolute terms, the decline in emissions of almost 2 000 million tonnes of CO_2 is without precedent in human history – broadly speaking, this is the equivalent of removing all of the European Union's emissions from the global total. Demand for fossil fuels was hardest hit in 2020 – especially oil, which plunged 8.6%, and coal, which dropped by 4%. Oil's annual decline was its largest ever, accounting for more than half of the drop in global emissions. Global emissions from oil use plummeted by well over 1 100 Mt CO_2, down from around 11 400 Mt in 2019. The drop in road transport activity accounted for 50% of the

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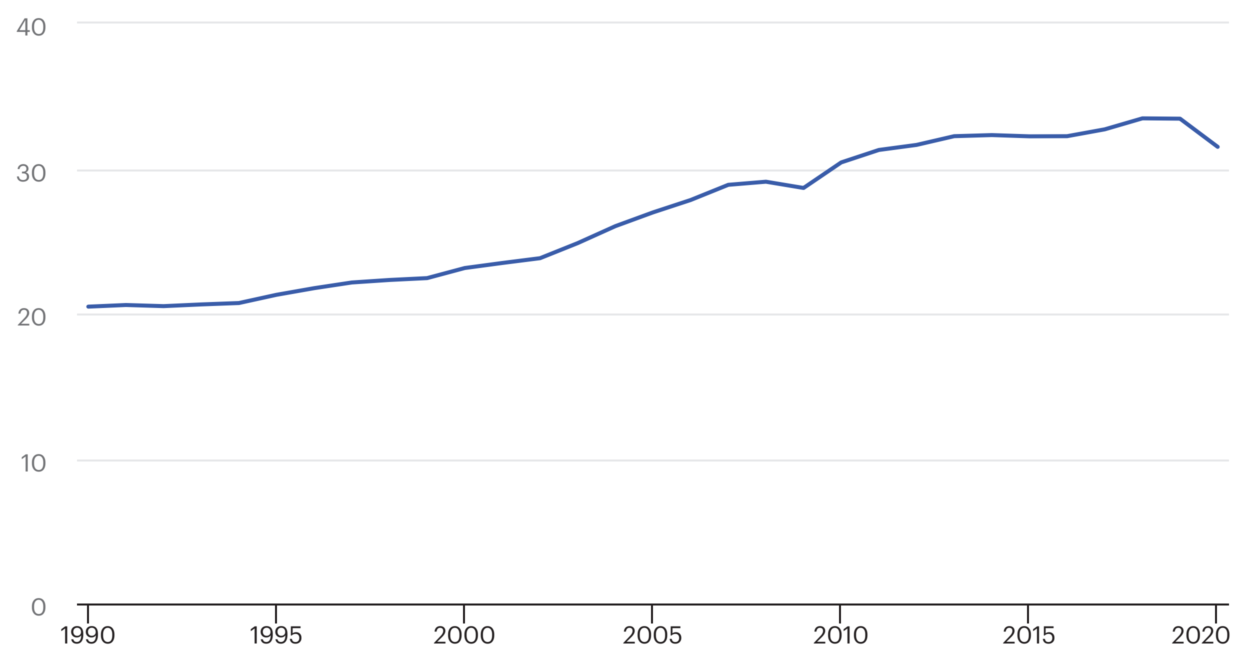
decline in global oil demand, and the slump in the aviation sector for around 35%. Meanwhile, low-carbon fuels and technologies, in particular, solar PV and wind, reached their highest ever annual share of the global energy mix, increasing it by more than one percentage point to over 20%.

Global energy-related CO2 emissions, 1990-2020

Open

Gt CO2



Change in CO2 emissions by fuel, 1990-2020

Open

Gt CO2

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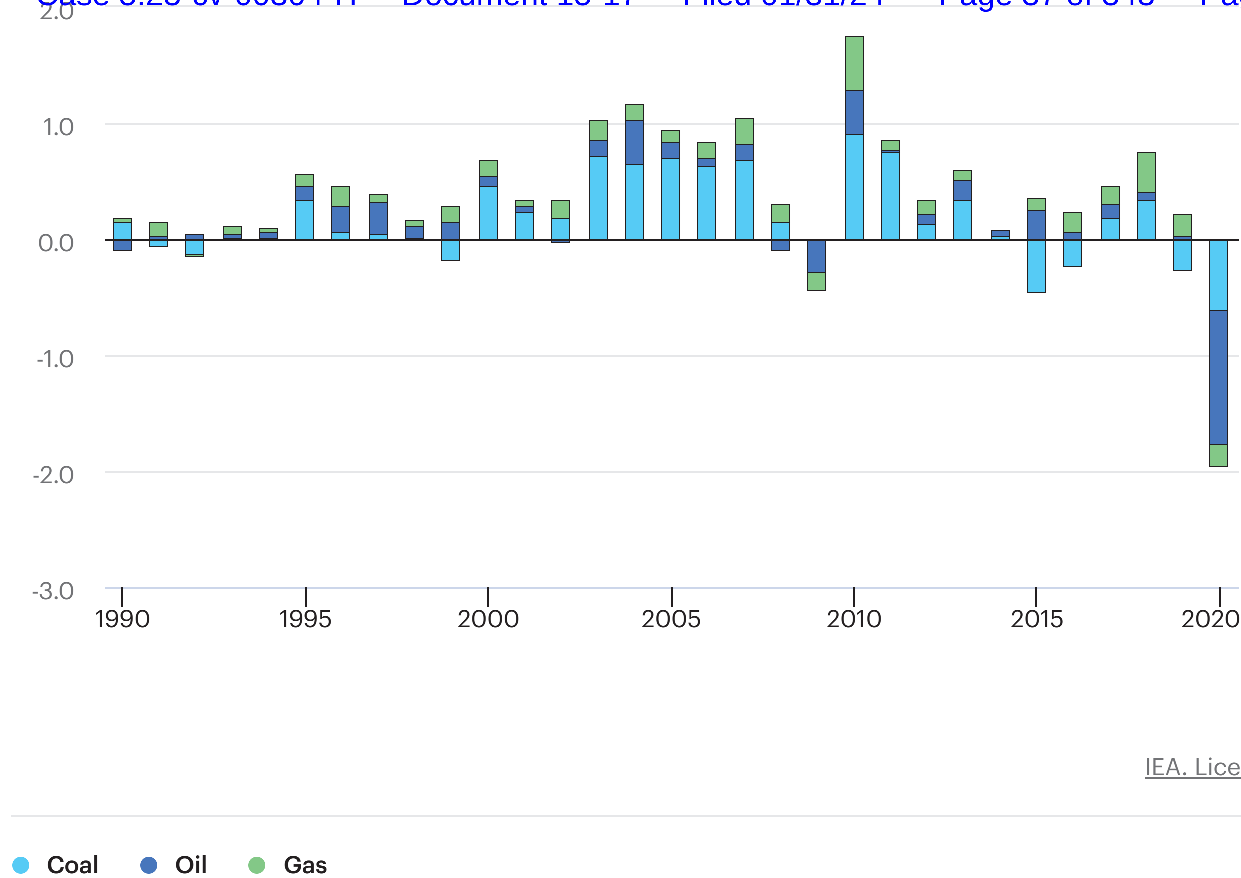


Transport sees the biggest decline

A common theme across all economies is the scale of the impact of the pandemic and lockdown measures on transport activity. The decline in CO2 emissions from oil use in the **transport** sector accounted for well over 50% of the total global drop in CO2 emissions in 2020, with restrictions on movement at local and international levels leading to a near 1 100 Mt drop in emissions from the sector, down almost 14% from 2019 levels. With various travel advisories and border restrictions, international aviation was the sector hardest hit in 2020, with global flight activity reaching a low in April 2020 of 70% below the level in the same month a year earlier. In contrast to pre-crisis levels, emissions from international aviation fell by almost 45% or 265 Mt CO2 across the year to a level last seen in 1999. This decline is equivalent to taking around 100 million conventional cars off the road.

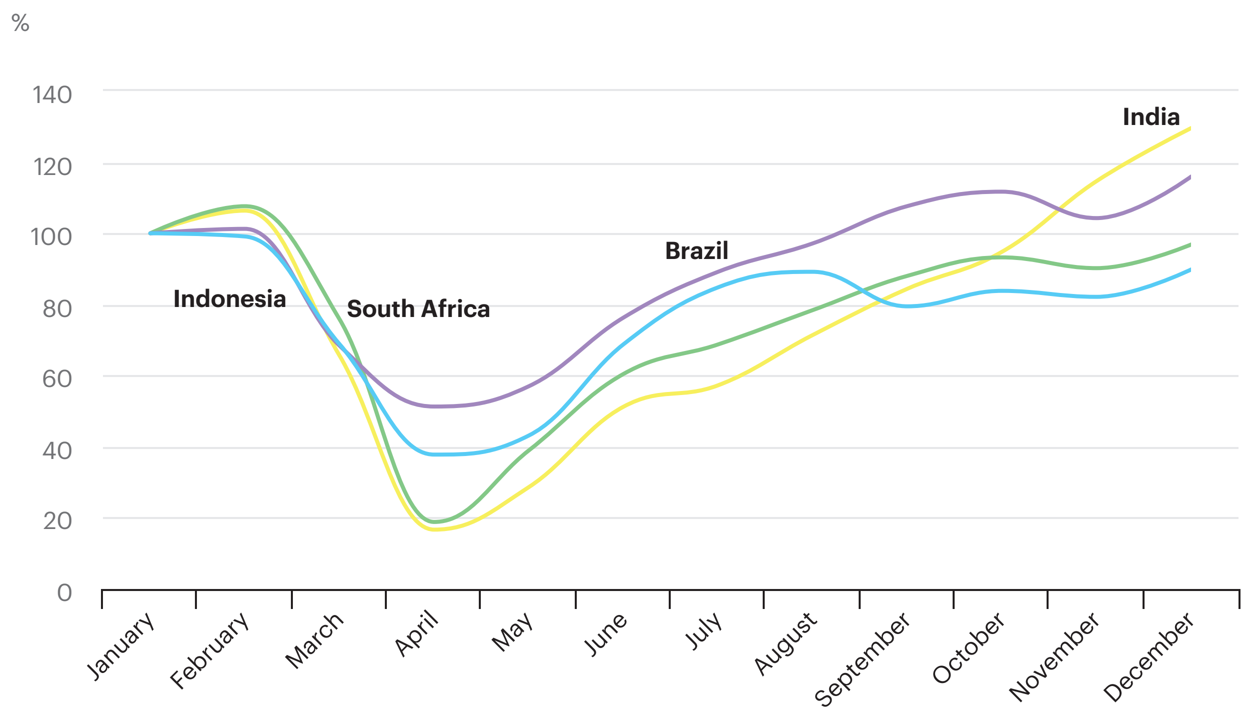
Road transport was also severely affected, with its demand for oil dropping 10% relative to 2019. The impact of the pandemic on global car sales was even greater: these fell by close to 15%. Electric cars bucked this trend, however, with their sales growing by more than 40% in 2020 to over 3 million, largely driven by policy support in the European Union and stimulus measures in the People's Republic of China ("China"). This is an encouraging sign for clean energy transitions globally, although emissions growth last year from the continued shift

towards larger vehicles such as SUVs offset the decrease in emissions from higher electric car sales.

With transport typically accounting for around 60% of oil demand, and the drop in oil demand contributing the largest share to the decline in 2020 emissions, the recovery of global transport activity is an important bellwether for the rebound in global oil demand and in global CO2 emissions. In emerging economies, the recovery of road transport activity through the second half of 2020 was one of the principal drivers of the rebound in emissions. In advanced economies, road transport activity remained suppressed through the second half of 2020 relative to 2019 levels.

Road transport activity for selected emerging economies in 2020

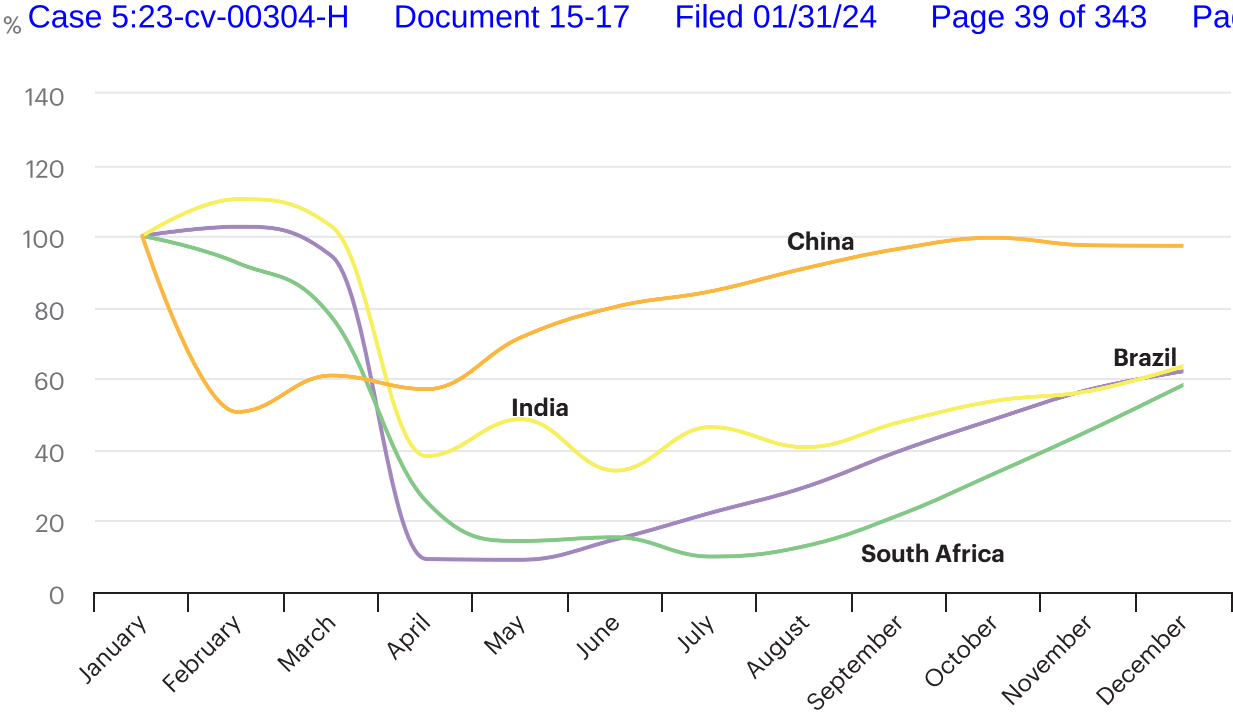
Open



Indonesia Brazil South Africa India

Aviation activity for selected emerging economies in 2020

Open



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China India South Africa Brazil

Power sector decarbonisation accelerates

In the power sector, CO_2 emissions declined by 3.3% (or 450 Mt) in 2020, the largest relative and absolute fall on record. While the pandemic reduced electricity demand last year, the accelerating expansion of power generation from renewables was the biggest contributor to lower emissions from the sector. The share of renewables in global electricity generation rose from 27% in 2019 to 29% in 2020, the biggest annual increase on record. Over the last ten years, the rise of renewables in the power sector has been having a growing impact on that sector's emissions, with avoided carbon emissions growing by an average 10% each year. Despite the shock of the pandemic, renewables accelerated their expansion in 2020, with a 50% increase in their contribution to lowering power sector emissions relative to 2019.

Global electricity generation mix, 2010-2020

Open

%

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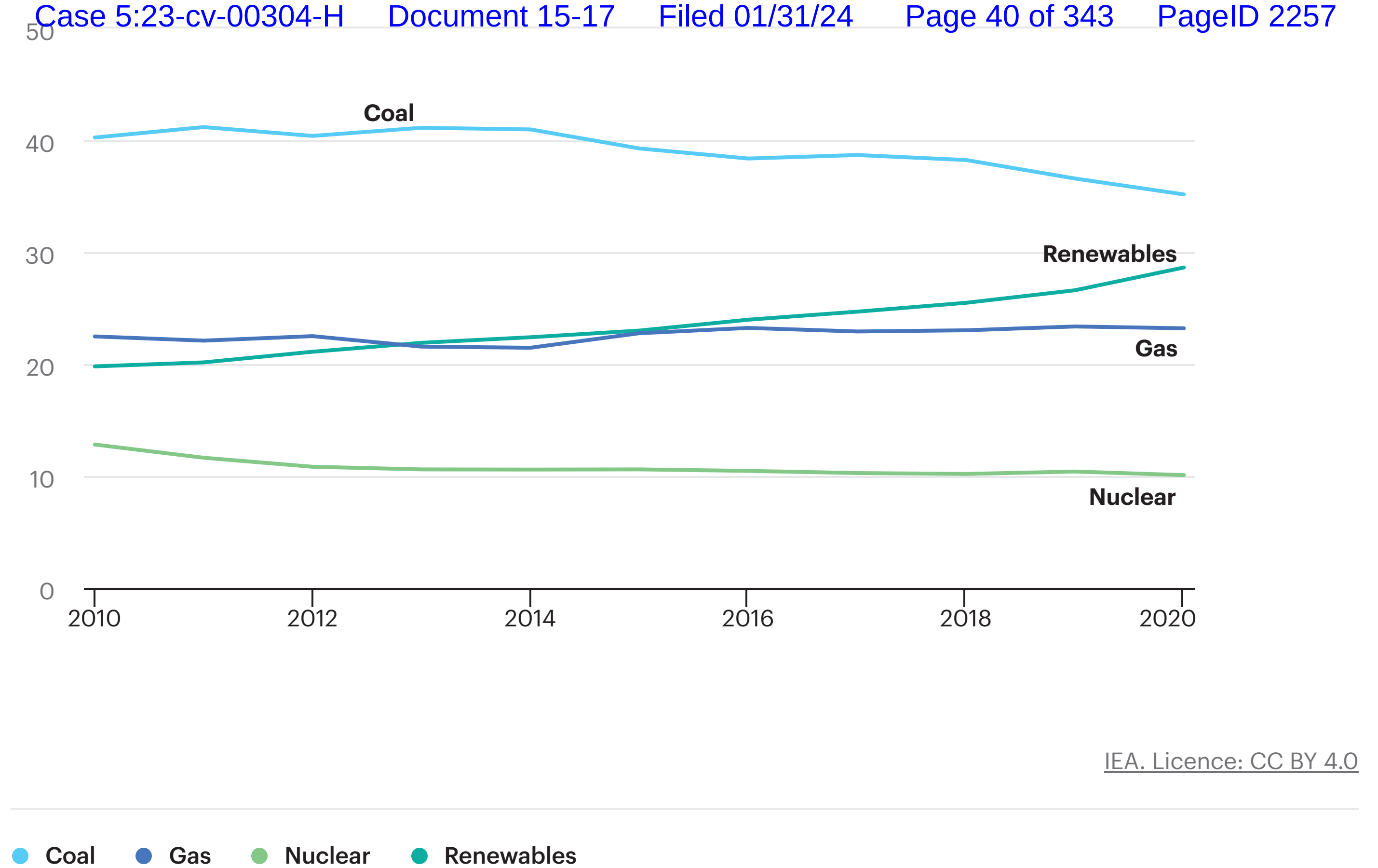
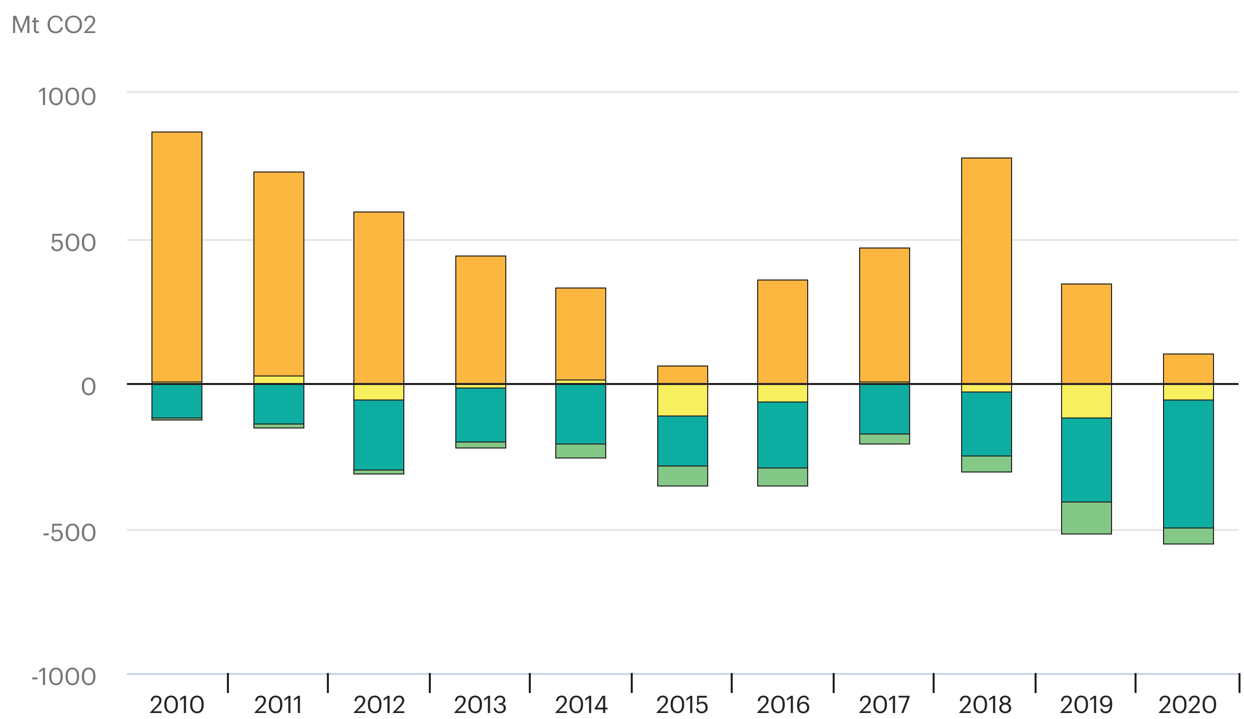


Change in power sector emissions by effect, 2010-2020

Open



Coal-to-gas Electricity demand Renewables Nuclear

Monthly data show a rapid recovery of economic activity and rebounding CO2 emissions

At a regional level, the different responses to the pandemic impacted emissions in different ways. On average, advanced economies saw the steepest declines in annual emissions in 2020, averaging drops of almost 10%, while emissions from emerging market and developing economies fell by 4% relative to 2019. Most economies saw a decline of five-to-ten percentage points compared to recent rates of emissions growth, with lesser declines in Brazil and most notably, China. The only major economy to record an increase in annual CO2 emissions in 2020, China's emissions growth slowed by just one percentage point compared with its average rate over the 2015 to 2019 period.

Change in annual CO2 emissions in selected regions and countries, 2020 and historically

Open

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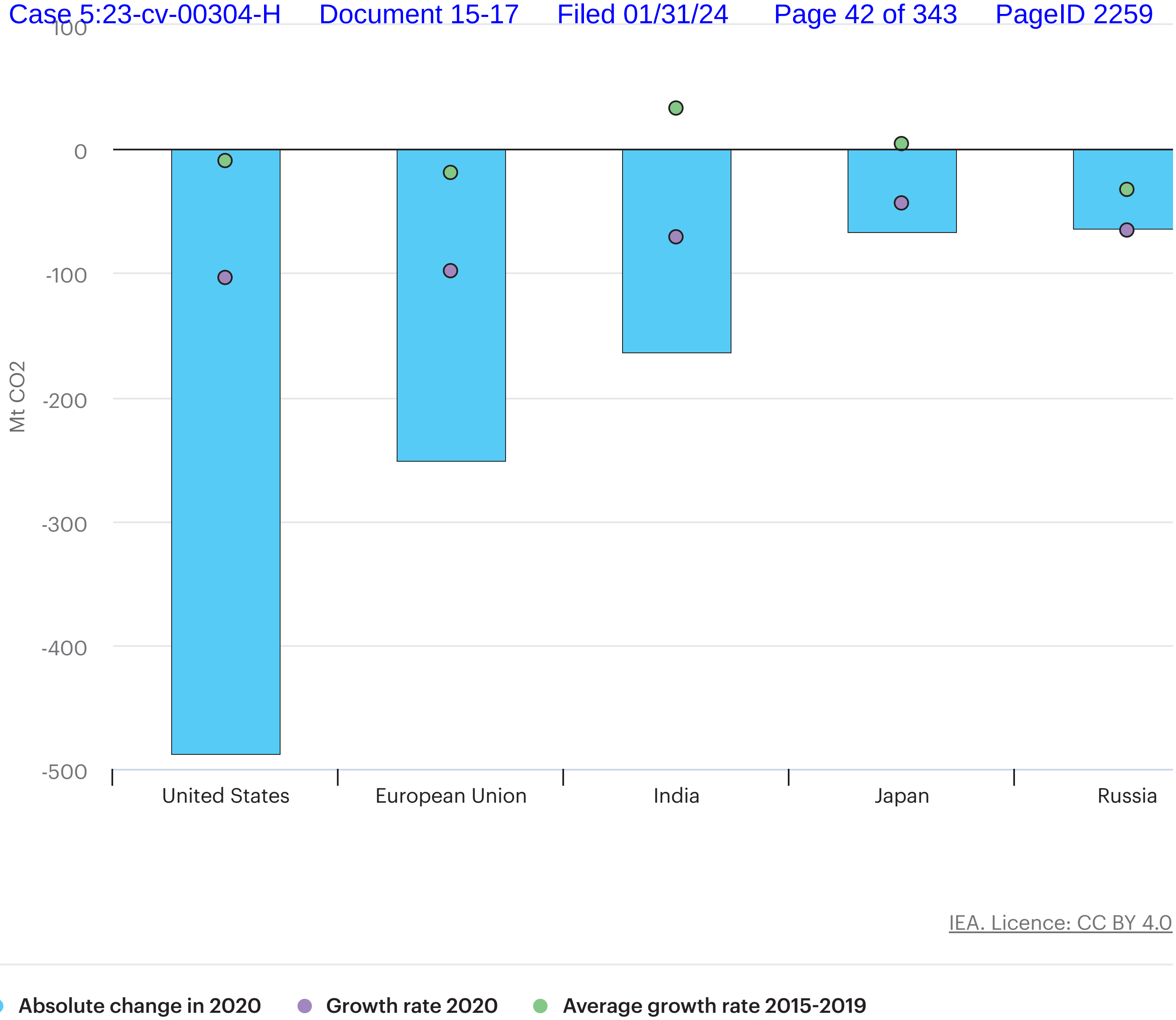
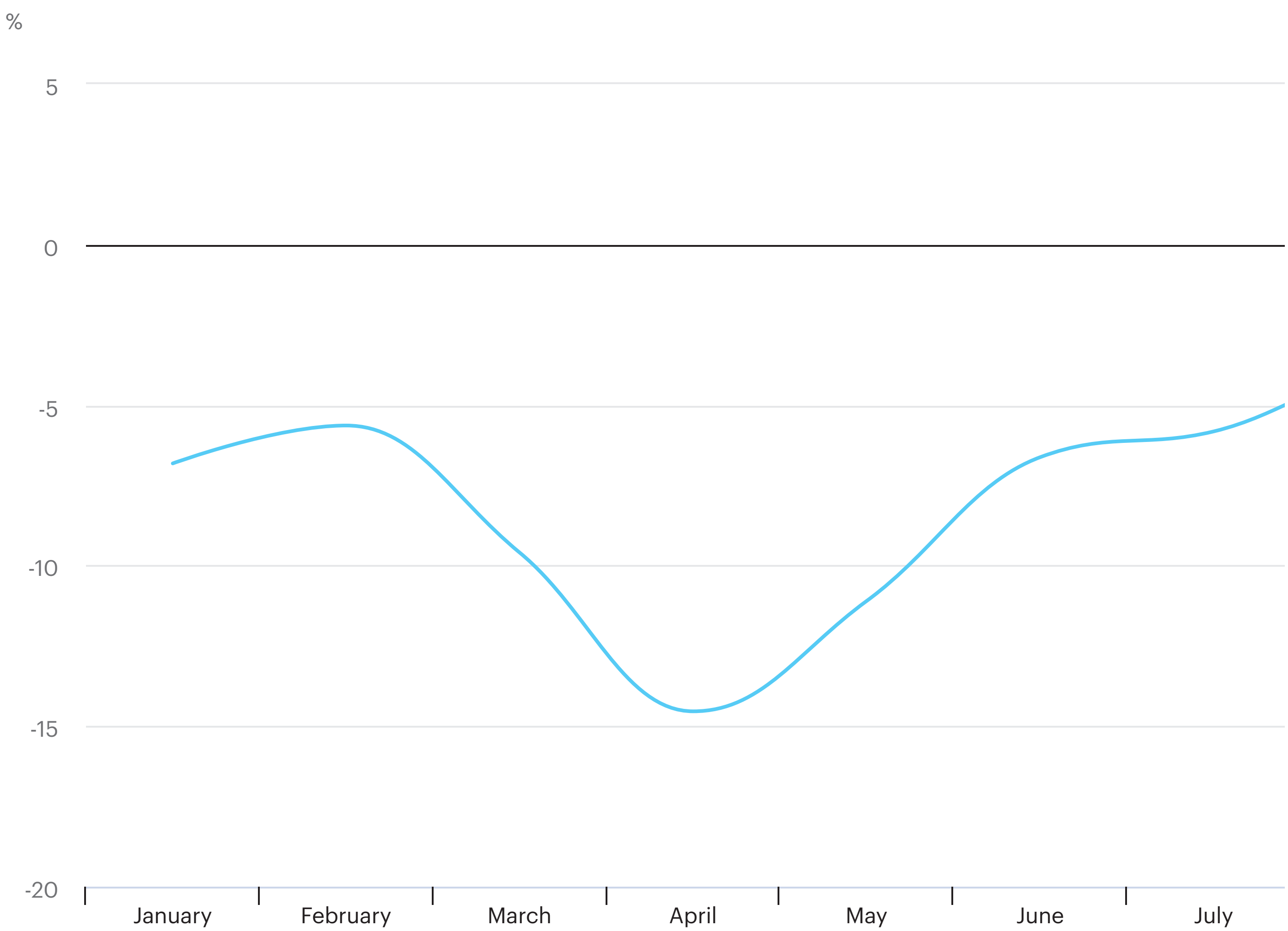


Last year, for the first time the IEA began to track energy demand and CO2 emissions trends on a monthly basis – and in some cases, in real-time. This provides a valuable tool for understanding the impacts of the pandemic on the energy sector. In January 2020, weather was the major driver of lower global CO2 emissions relative to 2019, with heating needs in major economies such as the United States, Germany, the United Kingdom and Russia 15% to 20% lower than in January 2019, due to milder-than-usual weather. The impact of the pandemic started to be felt in late February; and, by April, global emissions registered their largest monthly drop when a majority of advanced economies experienced various forms of restrictions on movement and travel. As the first wave of the pandemic was brought under control and economic activity increased towards the middle of the year, emissions

increased. They continued to rebound through the rest of the year. In December 2020, global emissions were 2% higher than they were in the same month a year earlier.

Monthly evolution of global CO2 emissions, 2020 relative to 2019

Open

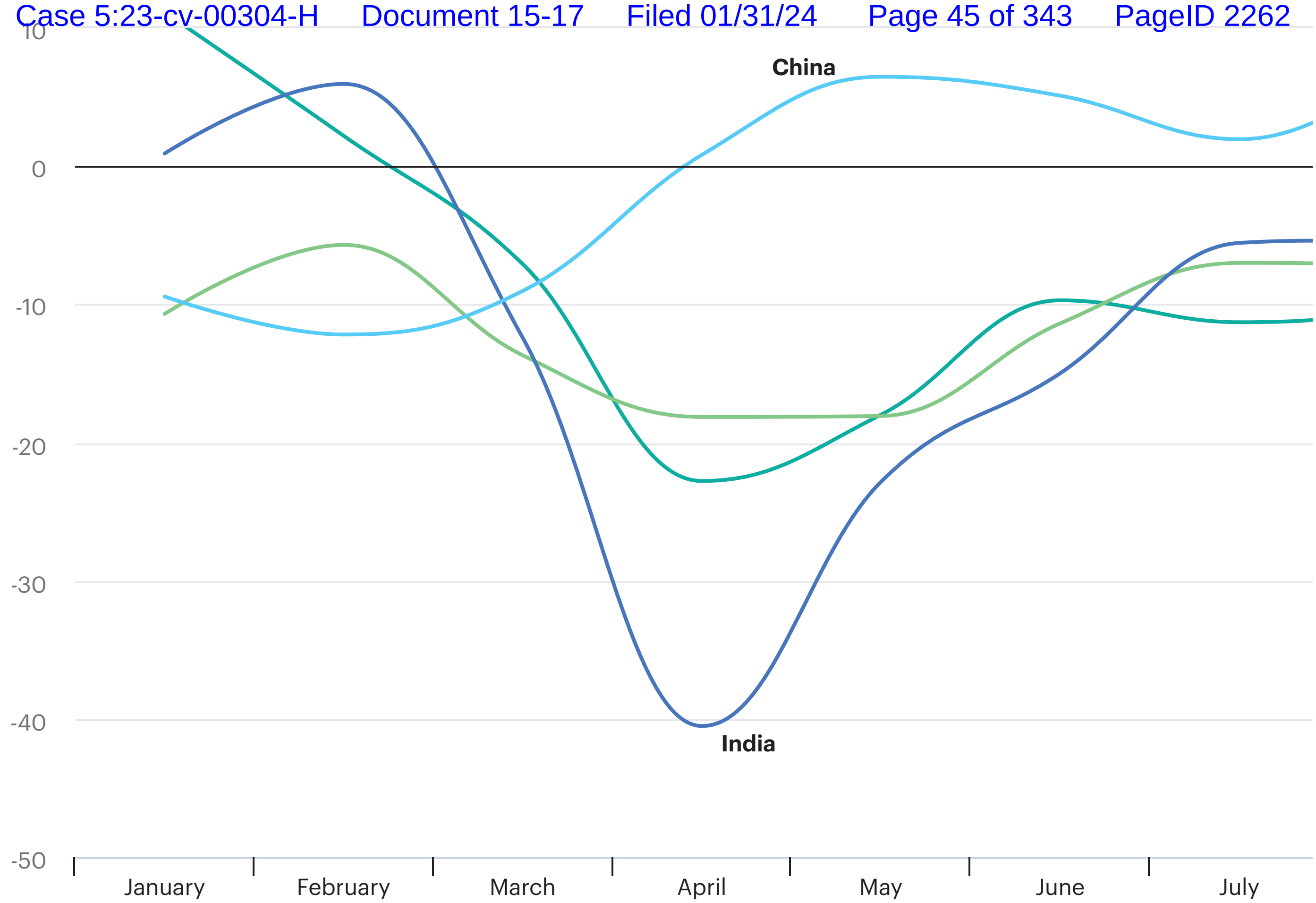


Regional differences

Major emitters underpinned the rebound of global CO_2 emissions in 2020, as a pick-up in economic activity boosted energy demand, with many economies already seeing emissions above pre-COVID levels. China, the first major economy to emerge from the pandemic and lift restrictions, saw a 7% increase in emissions in December 2020 compared with a year earlier. Emissions in India rose above 2019 levels in September as the economic environment improved and restrictions were relaxed. Meanwhile, the Diwali holiday period in November 2020 (rather than October, as in the previous year), as well as strikes in the agricultural sector, temporarily lowered energy demand and emissions in November. In Brazil, the recovery of road transport activity in September drove a recovery in oil demand, while increases in gas demand in the later months of 2020 pushed emissions above 2019 levels. Emissions in the United States fell by 10% in 2020. But on a monthly basis, after hitting their lowest levels in April and May, they started to bounce back. In December, US emissions were approaching the level seen in the same month the year before, as greater economic activity and the combination higher natural gas prices and of colder weather favoured an increase in coal use.

Monthly evolution of CO2 emissions in selected major economies, 2020 relative to 2019 **Open**

%



China India United States Brazil

In **China**, the world's largest CO2 emitter and the first country to be impacted by the Covid-19 pandemic, CO2 emissions dropped by 12% in February relative to the same month in 2019, as economic activity was curtailed. In April, China's economic recovery lifted its monthly CO2 emissions above their 2019 level. For the remainder of the year, emissions in China were on average 5% higher than 2019 levels. The latest annual figures indicate that the country's overall CO2 emissions in 2020 were 0.8% (or 75 Mt CO2) above the levels assessed at the end of 2019.

Monthly change in CO2 emissions in China in 2020 relative to 2019 Open

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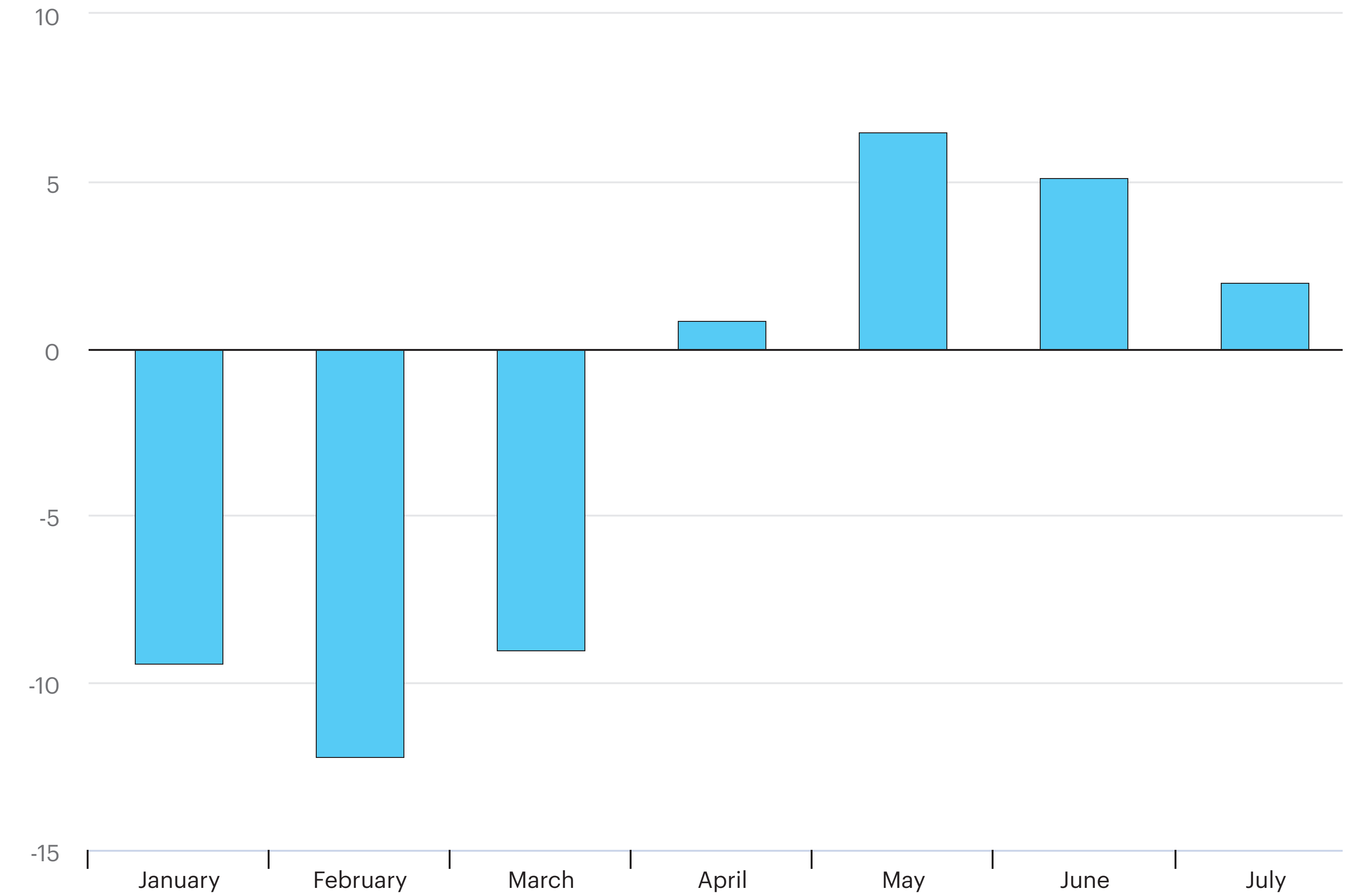

In **India,** annual CO2 emissions declined by 7% (or 160 Mt CO2) in 2020, a stark contrast with its average emissions growth of 3.3% from 2015 to 2019. With India's almost 1.4 billion citizens in total lockdown during April 2020, emissions in that month fell by a staggering 40% compared with April 2019, the largest decline in a single month experienced by any major economy. Annual emissions from coal-fired power plants across India fell by 5% relative to 2019, adjusting to lower electricity demand while generation from renewables grew by close to 4%, increasing their share in the generation mix to 22%. With most industrial production and freight transport coming to a standstill during the lockdown, annual emissions from the transport and industry sectors both declined by close to 50 Mt CO2. This resulted in the lowest recorded levels of air pollution in recent years in many major Indian

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cities. In September, a rebound in economic activity saw energy demand in India return to 2019 levels, albeit a low bar given the economic slowdown towards the end of 2019.

Monthly change in CO2 emissions in India in 2020 relative to 2019

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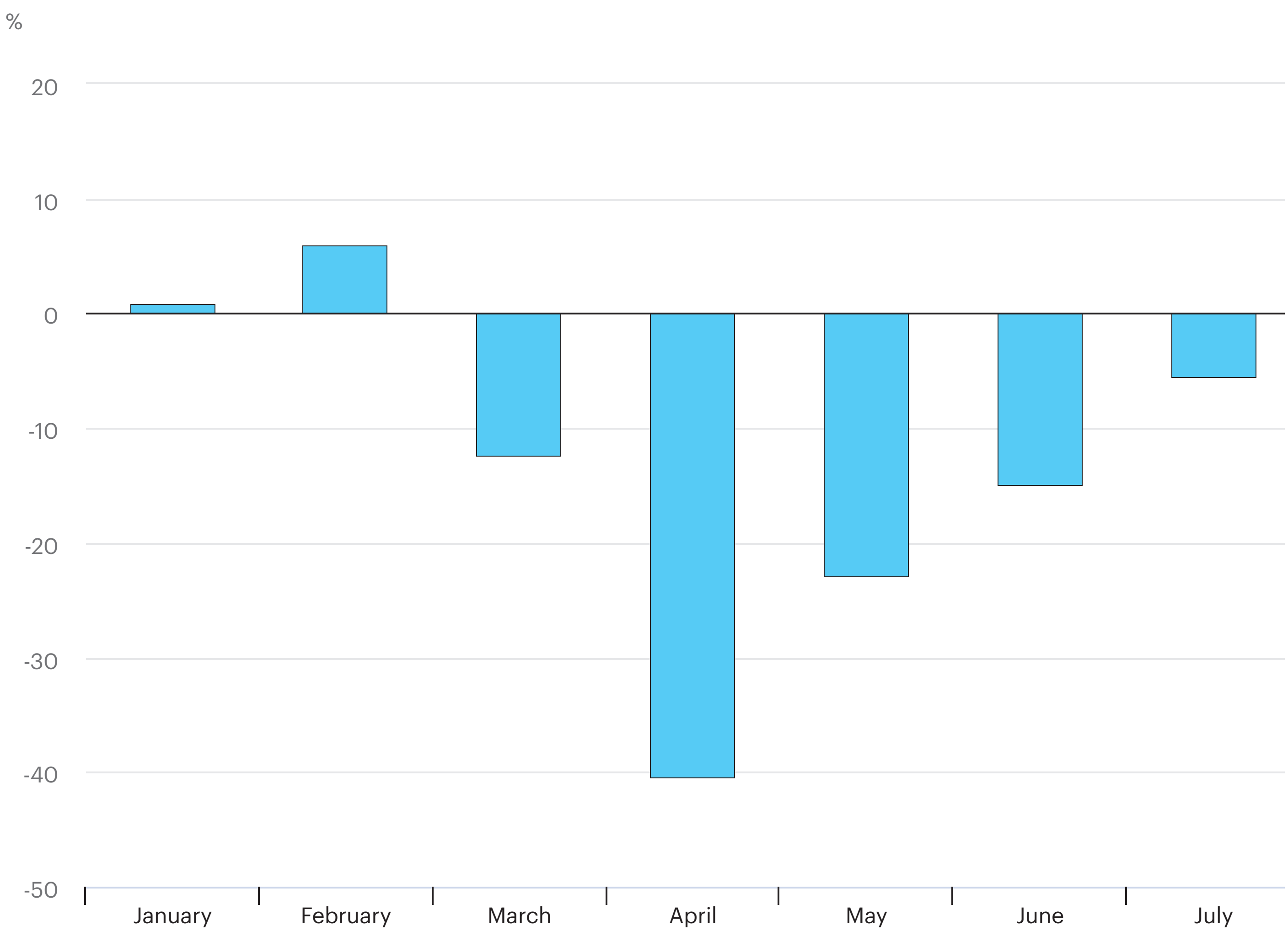


The impact of the pandemic on **advanced economies** endured well beyond the initial lockdowns of March and April. Economic activity remained at lower levels for much of the second half of the year and dropped again in the final months of 2020 as new restrictions on movement were imposed in many countries. Nonetheless, the impact of a second wave of

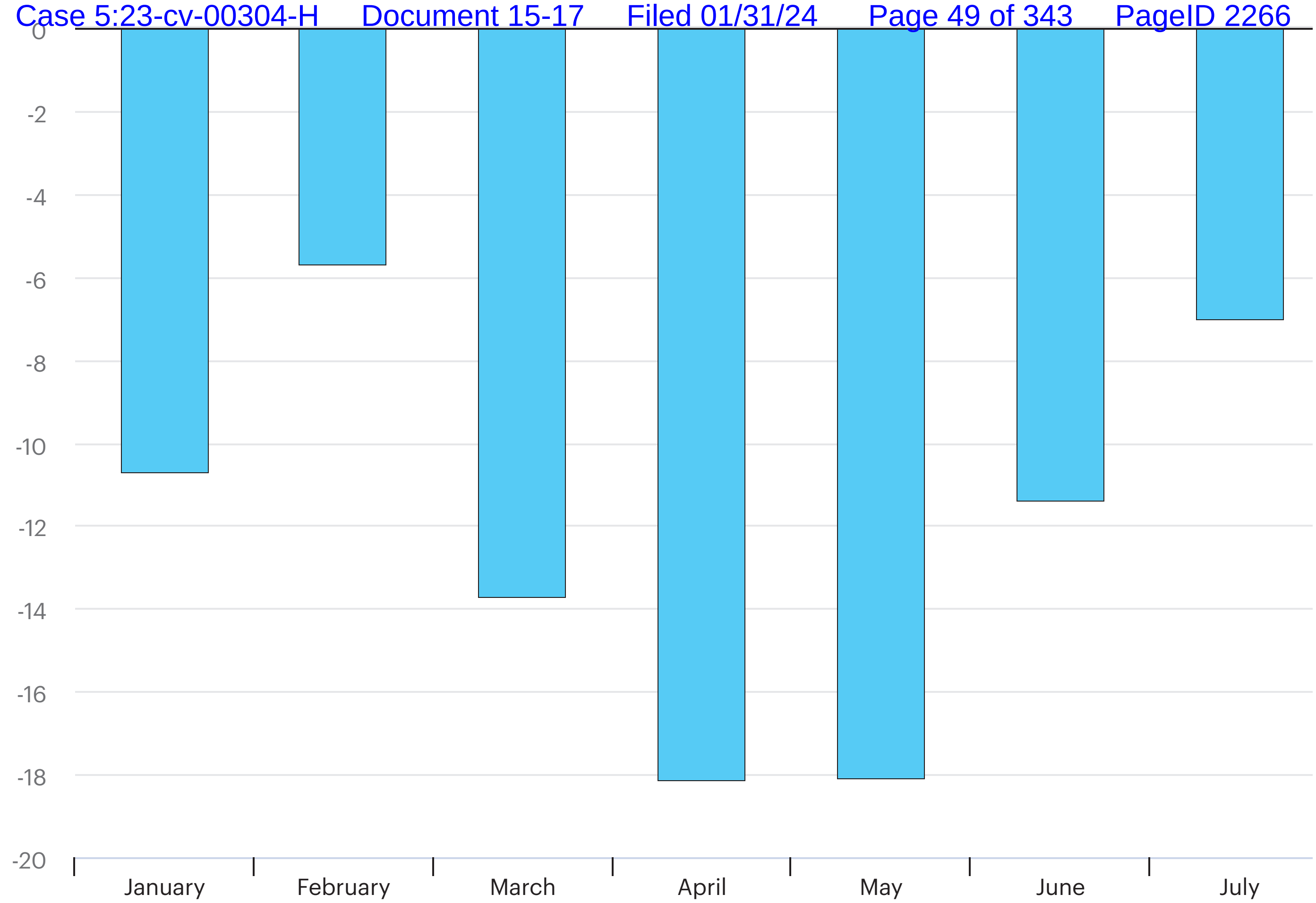
FHWA001987

lockdowns on energy demand was lower than that of earlier lockdowns, and many advanced economies are already well on the way to seeing a recovery in their emissions.

In the **United States**, the lack of national lockdowns mitigated the impact of the enduring health crisis on overall energy use and emissions. Nonetheless, stay-at-home orders in several states and the economic crisis induced by the pandemic led overall annual CO2 emissions to decline by more than 10%, or almost 500 Mt CO2. Transport emissions fell the most, with a 14% decline as activity plummeted in April. Emissions in the United States have been on a declining trend in recent years, largely due to changes in the power sector. With a strong coal-to-gas shift as natural gas prices have moved towards historic lows, and the rapid growth of renewables, emissions from coal-fired power generation declined 27% from 2015 to 2019. This trend accelerated in 2020, with monthly inflation adjusted gas prices hitting an all-time low of USD 1.63 per million British thermal units in June at Henry Hub, and lower electricity demand driving emissions from coal generation down by a further 20%. However, coal demand would have fallen even further if not for the increase in gas prices in the second half of the year and the subsequent reversal of some coal-to-gas switching. This trend combined with colder temperatures to push up emissions in December.

Monthly change in CO2 emissions in the United States in 2020 relative to 2019 **Open**

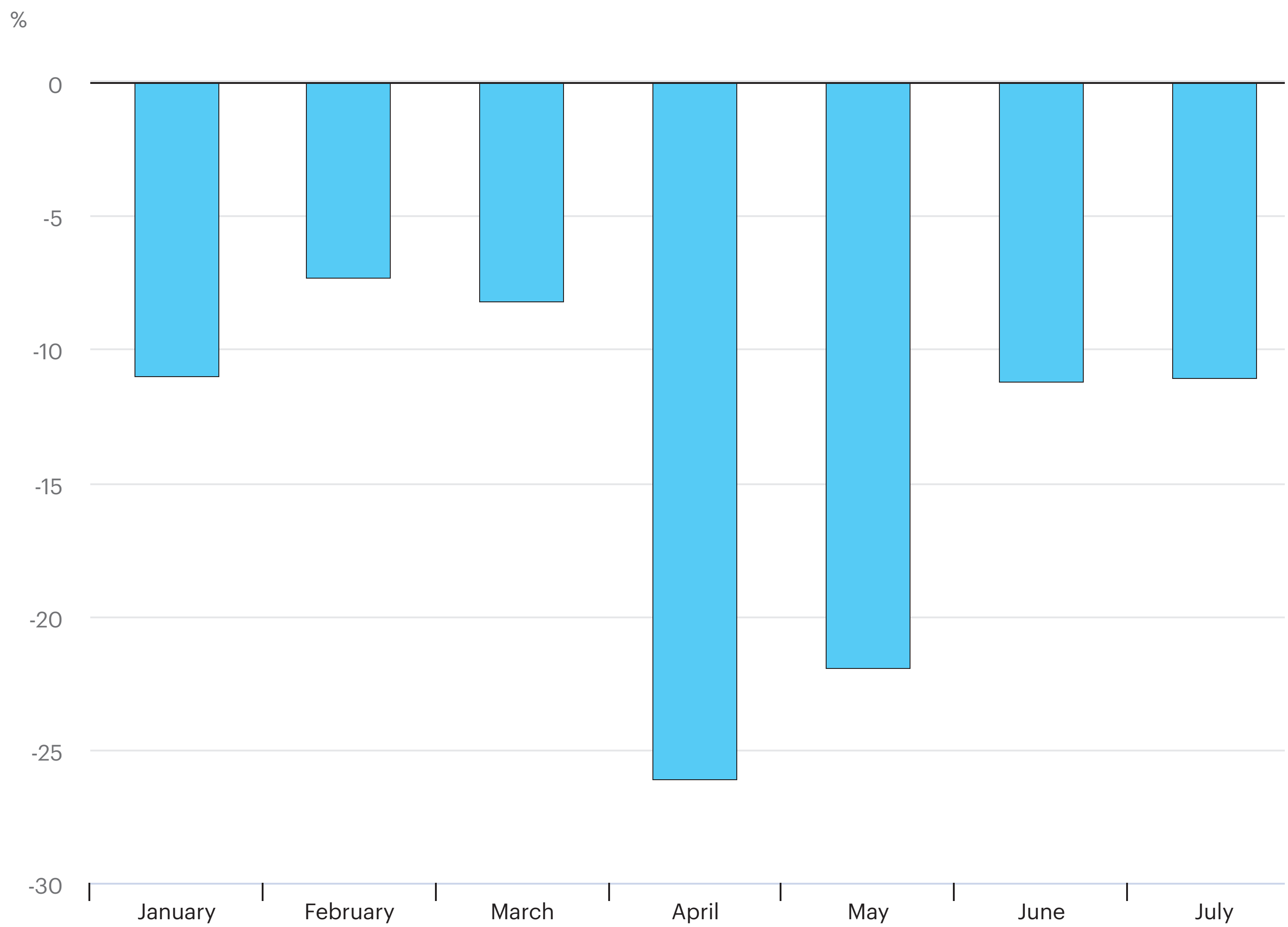
%



Across the **European Union**, a region that saw multiple restrictions and lockdowns being imposed in almost all member states, annual CO_2 emissions fell by 10% relative to 2019. Lower electricity demand across the bloc and an 8% increase in output from renewables drove a more than 20% decline in coal-fired power generation. As a result, the share of renewables in electricity generation increased to a record 39% in 2020, four percentage points higher than in 2019. Transport oil demand fell by 12%, a consequence of strict lockdown measures and restrictions on intra-European movement. In **Germany**, overall energy-related CO_2 emissions dropped by almost 9% in 2020, with generation from coal-fired power plants falling by over 20% due to lower electricity demand and higher output from wind and solar. In **France**, annual emissions were 11% lower than in 2019, with emissions from transport declining by almost 20 Mt CO_2 and accounting for 60% of the total reduction in France's emissions as a result of the two nationwide lockdowns in the spring and autumn.

Monthly change in CO_2 emissions in the European Union in 2020 relative to 2019

Open



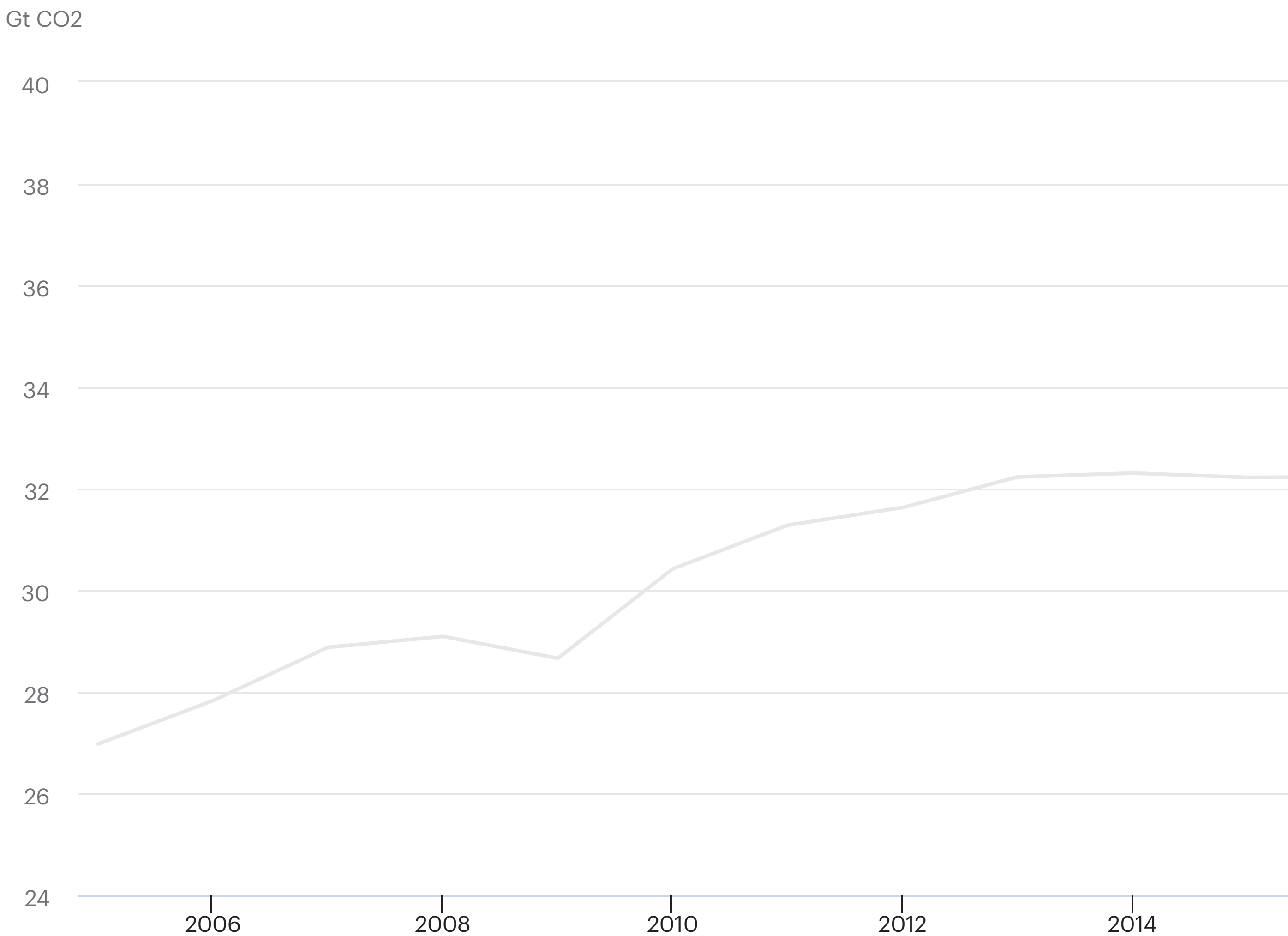
How will 2020 affect future emissions trends?

While 2020 marked the largest absolute decline in global CO_2 emissions in history, the evidence of a rapid rebound in energy demand and emissions in many economies underscores the risk that CO_2 emissions will increase significantly this year. What happens to energy demand and emissions in 2021 and beyond will depend on how much emphasis governments put on clean energy transitions in their efforts to boost their economies in the

coming months. Avoiding a rebound in emissions requires rapid structural changes in how we use and produce energy. The IEA Sustainable Recovery report, published in June 2020, outlined a pathway to avoid a rebound in emissions, with the Sustainable Recovery Plan providing clear recommendations on how to create jobs, boost economic growth and significantly reduce emissions simultaneously.

Total energy related CO2 emissions with and without a sustainable recovery, 2005-2023

Open



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Historical With a sustainable recovery Without a sustainable recovery

Ensuring that 2019 marks a definitive peak in global CO_2 emissions will be extremely challenging, but last year offers some valuable lessons that provide cause for optimism as we look ahead. Many power systems successfully kept the lights on, allowing hospitals to function or communication systems to operate with much higher shares of variable renewables. This provides a glimpse of things to come and offers greater confidence in operating large electricity systems powered with higher shares of renewables. Further, consumer preference for electric vehicles continues to grow, as does the number of electric vehicle models available.

Data sources and method

The IEA draws upon a wide range of respected statistical sources to construct estimates for the year 2020 and the month-to-month evolutions of energy demand and CO_2 emissions. Sources include the latest monthly data submissions to the IEA Energy Data Centre (including December 2020 when available), real-time data from power system operators across the world, other statistical releases from national administrations, and recent market data from the IEA Market Report Series that covers coal, oil, natural gas, renewables and electricity. Where data are not available on an annual or monthly basis, estimates may be used.

CO_2 emissions include emissions from all uses of fossil fuels for energy purposes. CO_2 emissions do not include emissions from industrial processes, industrial waste and non-renewable municipal waste. CO_2 emissions from international marine and aviation bunkers are included at the world level only.

The Energy Mix

FHWA001992

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Summary for Policymakers

SPM

Summary for Policymakers

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Introduction

This Report responds to the invitation for IPCC '... to provide a Special Report in 2018 on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways' contained in the Decision of the 21st Conference of Parties of the United Nations Framework Convention on Climate Change to adopt the Paris Agreement.[1]

The IPCC accepted the invitation in April 2016, deciding to prepare this Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

This Summary for Policymakers (SPM) presents the key findings of the Special Report, based on the assessment of the available scientific, technical and socio-economic literature[2] relevant to global warming of 1.5°C and for the comparison between global warming of 1.5°C and 2°C above pre-industrial levels. The level of confidence associated with each key finding is reported using the IPCC calibrated language.[3] The underlying scientific basis of each key finding is indicated by references provided to chapter elements. In the SPM, knowledge gaps are identified associated with the underlying chapters of the Report.

A. Understanding Global Warming of 1.5°C[4]

A.1 Human activities are estimated to have caused approximately 1.0°C of global warming[5] above pre-industrial levels, with a *likely* range of 0.8°C to 1.2°C. Global warming is *likely* to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. (*high confidence*) (Figure SPM.1) {1.2}

A.1.1 Reflecting the long-term warming trend since pre-industrial times, observed global mean surface temperature (GMST) for the decade 2006–2015 was 0.87°C (*likely* between 0.75°C and 0.99°C)[6] higher than the average over the 1850–1900 period (*very high confidence*). Estimated anthropogenic global warming matches the level of observed warming to within ±20% (*likely range*). Estimated anthropogenic global warming is currently increasing at 0.2°C (*likely* between 0.1°C and 0.3°C) per decade due to past and ongoing emissions (*high confidence*). {1.2.1, Table 1.1, 1.2.4}

A.1.2 Warming greater than the global annual average is being experienced in many land regions and seasons, including two to three times higher in the Arctic. Warming is generally higher over land than over the ocean. (*high confidence*) {1.2.1, 1.2.2, Figure 1.1, Figure 1.3, 3.3.1, 3.3.2}

A.1.3 Trends in intensity and frequency of some climate and weather extremes have been detected over time spans during which about 0.5°C of global warming occurred (*medium confidence*). This assessment is based on several lines of evidence, including attribution studies for changes in extremes since 1950. {3.3.1, 3.3.2, 3.3.3}

1 Decision 1/CP.21, paragraph 21.

2 The assessment covers literature accepted for publication by 15 May 2018.

3 Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, more unlikely than likely 0–<50%, extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, for example, *very likely*. This is consistent with AR5.

4 See also Box SPM.1: Core Concepts Central to this Special Report.

5 Present level of global warming is defined as the average of a 30-year period centred on 2017 assuming the recent rate of warming continues.

6 This range spans the four available peer-reviewed estimates of the observed GMST change and also accounts for additional uncertainty due to possible short-term natural variability. {1.2.1, Table 1.1}

A.2 Warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia and will continue to cause further long-term changes in the climate system, such as sea level rise, with associated impacts (*high confidence*), but these emissions alone are *unlikely* to cause global warming of 1.5°C (*medium confidence*). (Figure SPM.1) {1.2, 3.3, Figure 1.5}

A.2.1 Anthropogenic emissions (including greenhouse gases, aerosols and their precursors) up to the present are *unlikely* to cause further warming of more than 0.5°C over the next two to three decades (*high confidence*) or on a century time scale (*medium confidence*). {1.2.4, Figure 1.5}

A.2.2 Reaching and sustaining net zero global anthropogenic CO_2 emissions and declining net non-CO_2 radiative forcing would halt anthropogenic global warming on multi-decadal time scales (*high confidence*). The maximum temperature reached is then determined by cumulative net global anthropogenic CO_2 emissions up to the time of net zero CO_2 emissions (*high confidence*) and the level of non-CO_2 radiative forcing in the decades prior to the time that maximum temperatures are reached (*medium confidence*). On longer time scales, sustained net negative global anthropogenic CO_2 emissions and/or further reductions in non-CO_2 radiative forcing may still be required to prevent further warming due to Earth system feedbacks and to reverse ocean acidification (*medium confidence*) and will be required to minimize sea level rise (*high confidence*). {Cross-Chapter Box 2 in Chapter 1, 1.2.3, 1.2.4, Figure 1.4, 2.2.1, 2.2.2, 3.4.4.8, 3.4.5.1, 3.6.3.2}

A.3 Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2°C (*high confidence*). These risks depend on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of adaptation and mitigation options (*high confidence*). (Figure SPM.2) {1.3, 3.3, 3.4, 5.6}

A.3.1 Impacts on natural and human systems from global warming have already been observed (*high confidence*). Many land and ocean ecosystems and some of the services they provide have already changed due to global warming (*high confidence*). (Figure SPM.2) {1.4, 3.4, 3.5}

A.3.2 Future climate-related risks depend on the rate, peak and duration of warming. In the aggregate, they are larger if global warming exceeds 1.5°C before returning to that level by 2100 than if global warming gradually stabilizes at 1.5°C, especially if the peak temperature is high (e.g., about 2°C) (*high confidence*). Some impacts may be long-lasting or irreversible, such as the loss of some ecosystems (*high confidence*). {3.2, 3.4.4, 3.6.3, Cross-Chapter Box 8 in Chapter 3}

A.3.3 Adaptation and mitigation are already occurring (*high confidence*). Future climate-related risks would be reduced by the upscaling and acceleration of far-reaching, multilevel and cross-sectoral climate mitigation and by both incremental and transformational adaptation (*high confidence*). {1.2, 1.3, Table 3.5, 4.2.2, Cross-Chapter Box 9 in Chapter 4, Box 4.2, Box 4.3, Box 4.6, 4.3.1, 4.3.2, 4.3.3, 4.3.4, 4.3.5, 4.4.1, 4.4.4, 4.4.5, 4.5.3}

Cumulative emissions of CO_2 and future non-CO_2 radiative forcing determine the probability of limiting warming to 1.5°C

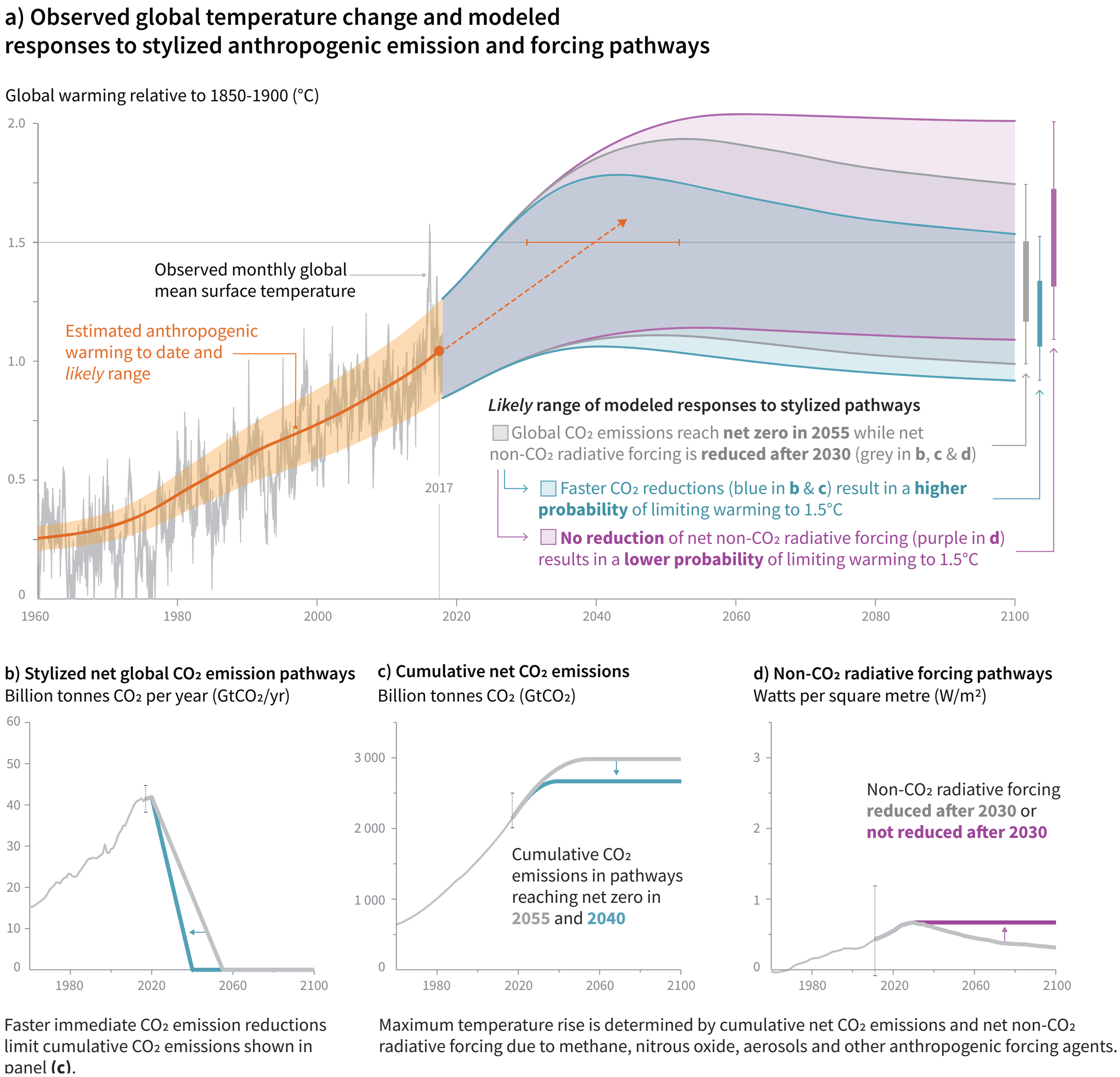


Figure SPM.1 | Panel a: Observed monthly global mean surface temperature (GMST, grey line up to 2017, from the HadCRUT4, GISTEMP, Cowtan–Way, and NOAA datasets) change and estimated anthropogenic global warming (solid orange line up to 2017, with orange shading indicating assessed *likely* range). Orange dashed arrow and horizontal orange error bar show respectively the central estimate and *likely* range of the time at which 1.5°C is reached if the current rate of warming continues. The grey plume on the right of panel a shows the *likely* range of warming responses, computed with a simple climate model, to a stylized pathway (hypothetical future) in which net CO_2 emissions (grey line in panels b and c) decline in a straight line from 2020 to reach net zero in 2055 and net non-CO_2 radiative forcing (grey line in panel d) increases to 2030 and then declines. The blue plume in panel a) shows the response to faster CO_2 emissions reductions (blue line in panel b), reaching net zero in 2040, reducing cumulative CO_2 emissions (panel c). The purple plume shows the response to net CO_2 emissions declining to zero in 2055, with net non-CO_2 forcing remaining constant after 2030. The vertical error bars on right of panel a) show the *likely* ranges (thin lines) and central terciles (33rd – 66th percentiles, thick lines) of the estimated distribution of warming in 2100 under these three stylized pathways. Vertical dotted error bars in panels b, c and d show the *likely* range of historical annual and cumulative global net CO_2 emissions in 2017 (data from the Global Carbon Project) and of net non-CO_2 radiative forcing in 2011 from AR5, respectively. Vertical axes in panels c and d are scaled to represent approximately equal effects on GMST. {1.2.1, 1.2.3, 1.2.4, 2.3, Figure 1.2 and Chapter 1 Supplementary Material, Cross-Chapter Box 2 in Chapter 1}

B. Projected Climate Change, Potential Impacts and Associated Risks

B.1 Climate models project robust[7] differences in regional climate characteristics between present-day and global warming of 1.5°C,[8] and between 1.5°C and 2°C.[8] These differences include increases in: mean temperature in most land and ocean regions (*high confidence*), hot extremes in most inhabited regions (*high confidence*), heavy precipitation in several regions (*medium confidence*), and the probability of drought and precipitation deficits in some regions (*medium confidence*). {3.3}

B.1.1 Evidence from attributed changes in some climate and weather extremes for a global warming of about 0.5°C supports the assessment that an additional 0.5°C of warming compared to present is associated with further detectable changes in these extremes (*medium confidence*). Several regional changes in climate are assessed to occur with global warming up to 1.5°C compared to pre-industrial levels, including warming of extreme temperatures in many regions (*high confidence*), increases in frequency, intensity, and/or amount of heavy precipitation in several regions (*high confidence*), and an increase in intensity or frequency of droughts in some regions (*medium confidence*). {3.2, 3.3.1, 3.3.2, 3.3.3, 3.3.4, Table 3.2}

B.1.2 Temperature extremes on land are projected to warm more than GMST (*high confidence*): extreme hot days in mid-latitudes warm by up to about 3°C at global warming of 1.5°C and about 4°C at 2°C, and extreme cold nights in high latitudes warm by up to about 4.5°C at 1.5°C and about 6°C at 2°C (*high confidence*). The number of hot days is projected to increase in most land regions, with highest increases in the tropics (*high confidence*). {3.3.1, 3.3.2, Cross-Chapter Box 8 in Chapter 3}

B.1.3 Risks from droughts and precipitation deficits are projected to be higher at 2°C compared to 1.5°C of global warming in some regions (*medium confidence*). Risks from heavy precipitation events are projected to be higher at 2°C compared to 1.5°C of global warming in several northern hemisphere high-latitude and/or high-elevation regions, eastern Asia and eastern North America (*medium confidence)*. Heavy precipitation associated with tropical cyclones is projected to be higher at 2°C compared to 1.5°C global warming (*medium confidence*). There is generally *low confidence* in projected changes in heavy precipitation at 2°C compared to 1.5°C in other regions. Heavy precipitation when aggregated at global scale is projected to be higher at 2°C than at 1.5°C of global warming (*medium confidence*). As a consequence of heavy precipitation, the fraction of the global land area affected by flood hazards is projected to be larger at 2°C compared to 1.5°C of global warming (*medium confidence*). {3.3.1, 3.3.3, 3.3.4, 3.3.5, 3.3.6}

B.2 By 2100, global mean sea level rise is projected to be around 0.1 metre lower with global warming of 1.5°C compared to 2°C (*medium confidence*). Sea level will continue to rise well beyond 2100 (*high confidence*), and the magnitude and rate of this rise depend on future emission pathways. A slower rate of sea level rise enables greater opportunities for adaptation in the human and ecological systems of small islands, low-lying coastal areas and deltas (*medium confidence*). {3.3, 3.4, 3.6}

B.2.1 Model-based projections of global mean sea level rise (relative to 1986–2005) suggest an indicative range of 0.26 to 0.77 m by 2100 for 1.5°C of global warming, 0.1 m (0.04–0.16 m) less than for a global warming of 2°C (*medium confidence*). A reduction of 0.1 m in global sea level rise implies that up to 10 million fewer people would be exposed to related risks, based on population in the year 2010 and assuming no adaptation (*medium confidence*). {3.4.4, 3.4.5, 4.3.2}

B.2.2 Sea level rise will continue beyond 2100 even if global warming is limited to 1.5°C in the 21st century (*high confidence*). Marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could result in multi-metre rise in sea level over hundreds to thousands of years. These instabilities could be triggered at around 1.5°C to 2°C of global warming (*medium confidence*). (Figure SPM.2) {3.3.9, 3.4.5, 3.5.2, 3.6.3, Box 3.3}

7 Robust is here used to mean that at least two thirds of climate models show the same sign of changes at the grid point scale, and that differences in large regions are statistically significant.

8 Projected changes in impacts between different levels of global warming are determined with respect to changes in global mean surface air temperature.

B.2.3 Increasing warming amplifies the exposure of small islands, low-lying coastal areas and deltas to the risks associated with sea level rise for many human and ecological systems, including increased saltwater intrusion, flooding and damage to infrastructure (*high confidence*). Risks associated with sea level rise are higher at 2°C compared to 1.5°C. The slower rate of sea level rise at global warming of 1.5°C reduces these risks, enabling greater opportunities for adaptation including managing and restoring natural coastal ecosystems and infrastructure reinforcement (*medium confidence*). (Figure SPM.2) {3.4.5, Box 3.5}

B.3 On land, impacts on biodiversity and ecosystems, including species loss and extinction, are projected to be lower at 1.5°C of global warming compared to 2°C. Limiting global warming to 1.5°C compared to 2°C is projected to lower the impacts on terrestrial, freshwater and coastal ecosystems and to retain more of their services to humans (*high confidence*). (Figure SPM.2) {3.4, 3.5, Box 3.4, Box 4.2, Cross-Chapter Box 8 in Chapter 3}

B.3.1 Of 105,000 species studied,[9] 6% of insects, 8% of plants and 4% of vertebrates are projected to lose over half of their climatically determined geographic range for global warming of 1.5°C, compared with 18% of insects, 16% of plants and 8% of vertebrates for global warming of 2°C (*medium confidence*). Impacts associated with other biodiversity-related risks such as forest fires and the spread of invasive species are lower at 1.5°C compared to 2°C of global warming (*high confidence*). {3.4.3, 3.5.2}

B.3.2 Approximately 4% (interquartile range 2–7%) of the global terrestrial land area is projected to undergo a transformation of ecosystems from one type to another at 1°C of global warming, compared with 13% (interquartile range 8–20%) at 2°C (*medium confidence*). This indicates that the area at risk is projected to be approximately 50% lower at 1.5°C compared to 2°C (*medium confidence*). {3.4.3.1, 3.4.3.5}

B.3.3 High-latitude tundra and boreal forests are particularly at risk of climate change-induced degradation and loss, with woody shrubs already encroaching into the tundra (*high confidence*) and this will proceed with further warming. Limiting global warming to 1.5°C rather than 2°C is projected to prevent the thawing over centuries of a permafrost area in the range of 1.5 to 2.5 million km^2 (*medium confidence*). {3.3.2, 3.4.3, 3.5.5}

B.4 Limiting global warming to 1.5°C compared to 2°C is projected to reduce increases in ocean temperature as well as associated increases in ocean acidity and decreases in ocean oxygen levels (*high confidence*). Consequently, limiting global warming to 1.5°C is projected to reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans, as illustrated by recent changes to Arctic sea ice and warm-water coral reef ecosystems (*high confidence*). {3.3, 3.4, 3.5, Box 3.4, Box 3.5}

B.4.1 There is *high confidence* that the probability of a sea ice-free Arctic Ocean during summer is substantially lower at global warming of 1.5°C when compared to 2°C. With 1.5°C of global warming, one sea ice-free Arctic summer is projected per century. This likelihood is increased to at least one per decade with 2°C global warming. Effects of a temperature overshoot are reversible for Arctic sea ice cover on decadal time scales (*high confidence*). {3.3.8, 3.4.4.7}

B.4.2 Global warming of 1.5°C is projected to shift the ranges of many marine species to higher latitudes as well as increase the amount of damage to many ecosystems. It is also expected to drive the loss of coastal resources and reduce the productivity of fisheries and aquaculture (especially at low latitudes). The risks of climate-induced impacts are projected to be higher at 2°C than those at global warming of 1.5°C (*high confidence*). Coral reefs, for example, are projected to decline by a further 70–90% at 1.5°C (*high confidence*) with larger losses (>99%) at 2°C (*very high confidence*). The risk of irreversible loss of many marine and coastal ecosystems increases with global warming, especially at 2°C or more (*high confidence*). {3.4.4, Box 3.4}

9 Consistent with earlier studies, illustrative numbers were adopted from one recent meta-study.

SPM

B.4.3 The level of ocean acidification due to increasing CO_2 concentrations associated with global warming of 1.5°C is projected to amplify the adverse effects of warming, and even further at 2°C, impacting the growth, development, calcification, survival, and thus abundance of a broad range of species, for example, from algae to fish (*high confidence*). {3.3.10, 3.4.4}

B.4.4 Impacts of climate change in the ocean are increasing risks to fisheries and aquaculture via impacts on the physiology, survivorship, habitat, reproduction, disease incidence, and risk of invasive species (*medium confidence*) but are projected to be less at 1.5°C of global warming than at 2°C. One global fishery model, for example, projected a decrease in global annual catch for marine fisheries of about 1.5 million tonnes for 1.5°C of global warming compared to a loss of more than 3 million tonnes for 2°C of global warming (*medium confidence*). {3.4.4, Box 3.4}

B.5 Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5°C and increase further with 2°C. (Figure SPM.2) {3.4, 3.5, 5.2, Box 3.2, Box 3.3, Box 3.5, Box 3.6, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5, 5.2}

B.5.1 Populations at disproportionately higher risk of adverse consequences with global warming of 1.5°C and beyond include disadvantaged and vulnerable populations, some indigenous peoples, and local communities dependent on agricultural or coastal livelihoods (*high confidence*). Regions at disproportionately higher risk include Arctic ecosystems, dryland regions, small island developing states, and Least Developed Countries (*high confidence*). Poverty and disadvantage are expected to increase in some populations as global warming increases; limiting global warming to 1.5°C, compared with 2°C, could reduce the number of people both exposed to climate-related risks and susceptible to poverty by up to several hundred million by 2050 (*medium confidence*). {3.4.10, 3.4.11, Box 3.5, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5, 4.2.2.2, 5.2.1, 5.2.2, 5.2.3, 5.6.3}

B.5.2 Any increase in global warming is projected to affect human health, with primarily negative consequences (*high confidence*). Lower risks are projected at 1.5°C than at 2°C for heat-related morbidity and mortality (*very high confidence*) and for ozone-related mortality if emissions needed for ozone formation remain high (*high confidence*). Urban heat islands often amplify the impacts of heatwaves in cities (*high confidence*). Risks from some vector-borne diseases, such as malaria and dengue fever, are projected to increase with warming from 1.5°C to 2°C, including potential shifts in their geographic range (*high confidence*). {3.4.7, 3.4.8, 3.5.5.8}

B.5.3 Limiting warming to 1.5°C compared with 2°C is projected to result in smaller net reductions in yields of maize, rice, wheat, and potentially other cereal crops, particularly in sub-Saharan Africa, Southeast Asia, and Central and South America, and in the CO_2-dependent nutritional quality of rice and wheat (*high confidence*). Reductions in projected food availability are larger at 2°C than at 1.5°C of global warming in the Sahel, southern Africa, the Mediterranean, central Europe, and the Amazon (*medium confidence*). Livestock are projected to be adversely affected with rising temperatures, depending on the extent of changes in feed quality, spread of diseases, and water resource availability (*high confidence*). {3.4.6, 3.5.4, 3.5.5, Box 3.1, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4}

B.5.4 Depending on future socio-economic conditions, limiting global warming to 1.5°C compared to 2°C may reduce the proportion of the world population exposed to a climate change-induced increase in water stress by up to 50%, although there is considerable variability between regions (*medium confidence*). Many small island developing states could experience lower water stress as a result of projected changes in aridity when global warming is limited to 1.5°C, as compared to 2°C (*medium confidence*). {3.3.5, 3.4.2, 3.4.8, 3.5.5, Box 3.2, Box 3.5, Cross-Chapter Box 9 in Chapter 4}

B.5.5 Risks to global aggregated economic growth due to climate change impacts are projected to be lower at 1.5°C than at 2°C by the end of this century[10] (*medium confidence*). This excludes the costs of mitigation, adaptation investments and the benefits of adaptation. Countries in the tropics and Southern Hemisphere subtropics are projected to experience the largest impacts on economic growth due to climate change should global warming increase from 1.5°C to 2°C (*medium confidence*). {3.5.2, 3.5.3}

10 Here, impacts on economic growth refer to changes in gross domestic product (GDP). Many impacts, such as loss of human lives, cultural heritage and ecosystem services, are difficult to value and monetize.

B.5.6 Exposure to multiple and compound climate-related risks increases between 1.5°C and 2°C of global warming, with greater proportions of people both so exposed and susceptible to poverty in Africa and Asia (*high confidence*). For global warming from 1.5°C to 2°C, risks across energy, food, and water sectors could overlap spatially and temporally, creating new and exacerbating current hazards, exposures, and vulnerabilities that could affect increasing numbers of people and regions (*medium confidence*). {Box 3.5, 3.3.1, 3.4.5.3, 3.4.5.6, 3.4.11, 3.5.4.9}

B.5.7 There are multiple lines of evidence that since AR5 the assessed levels of risk increased for four of the five Reasons for Concern (RFCs) for global warming to 2°C (*high confidence*). The risk transitions by degrees of global warming are now: from high to very high risk between 1.5°C and 2°C for RFC1 (Unique and threatened systems) (*high confidence*); from moderate to high risk between 1°C and 1.5°C for RFC2 (Extreme weather events) (*medium confidence*); from moderate to high risk between 1.5°C and 2°C for RFC3 (Distribution of impacts) (*high confidence*); from moderate to high risk between 1.5°C and 2.5°C for RFC4 (Global aggregate impacts) (*medium confidence*); and from moderate to high risk between 1°C and 2.5°C for RFC5 (Large-scale singular events) (*medium confidence*). (Figure SPM.2) {3.4.13; 3.5, 3.5.2}

B.6 Most adaptation needs will be lower for global warming of 1.5°C compared to 2°C (*high confidence*). There are a wide range of adaptation options that can reduce the risks of climate change (*high confidence*). There are limits to adaptation and adaptive capacity for some human and natural systems at global warming of 1.5°C, with associated losses (*medium confidence*). The number and availability of adaptation options vary by sector (*medium confidence*). {Table 3.5, 4.3, 4.5, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5}

B.6.1 A wide range of adaptation options are available to reduce the risks to natural and managed ecosystems (e.g., ecosystem-based adaptation, ecosystem restoration and avoided degradation and deforestation, biodiversity management, sustainable aquaculture, and local knowledge and indigenous knowledge), the risks of sea level rise (e.g., coastal defence and hardening), and the risks to health, livelihoods, food, water, and economic growth, especially in rural landscapes (e.g., efficient irrigation, social safety nets, disaster risk management, risk spreading and sharing, and community-based adaptation) and urban areas (e.g., green infrastructure, sustainable land use and planning, and sustainable water management) (*medium confidence*). {4.3.1, 4.3.2, 4.3.3, 4.3.5, 4.5.3, 4.5.4, 5.3.2, Box 4.2, Box 4.3, Box 4.6, Cross-Chapter Box 9 in Chapter 4}.

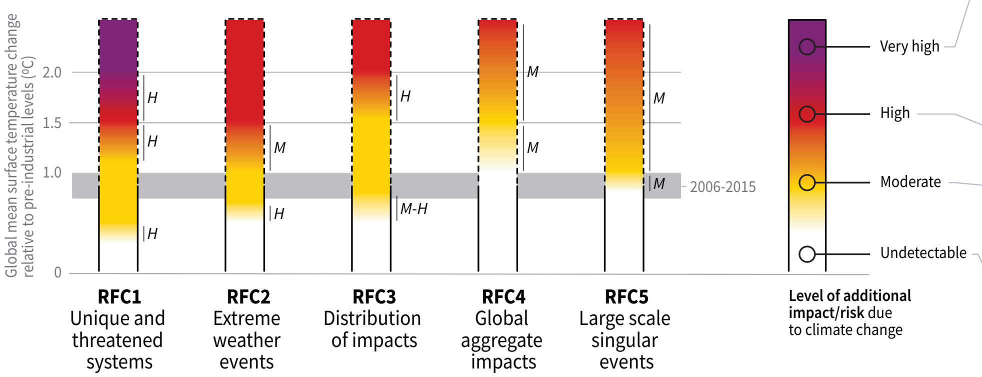
B.6.2 Adaptation is expected to be more challenging for ecosystems, food and health systems at 2°C of global warming than for 1.5°C (*medium confidence*). Some vulnerable regions, including small islands and Least Developed Countries, are projected to experience high multiple interrelated climate risks even at global warming of 1.5°C (*high confidence*). {3.3.1, 3.4.5, Box 3.5, Table 3.5, Cross-Chapter Box 9 in Chapter 4, 5.6, Cross-Chapter Box 12 in Chapter 5, Box 5.3}

B.6.3 Limits to adaptive capacity exist at 1.5°C of global warming, become more pronounced at higher levels of warming and vary by sector, with site-specific implications for vulnerable regions, ecosystems and human health (*medium confidence*). {Cross-Chapter Box 12 in Chapter 5, Box 3.5, Table 3.5}

How the level of global warming affects impacts and/or risks associated with the Reasons for Concern (RFCs) and selected natural, managed and human systems

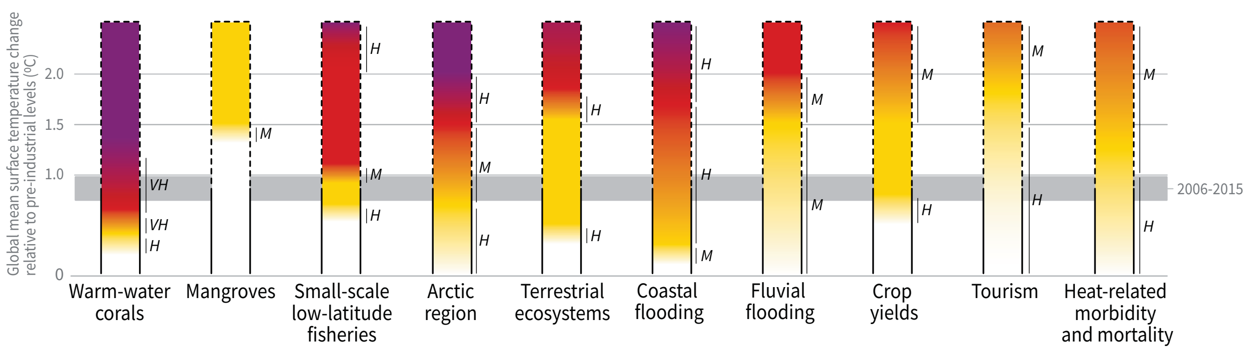
Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

Impacts and risks associated with the Reasons for Concern (RFCs)



Purple indicates very high risks of severe impacts/risks and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.
Red indicates severe and widespread impacts/risks.
Yellow indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.
White indicates that no impacts are detectable and attributable to climate change.

Impacts and risks for selected natural, managed and human systems



Confidence level for transition: *L*=Low, *M*=Medium, *H*=High and *VH*=Very high

Figure SPM.2 | Five integrative reasons for concern (RFCs) provide a framework for summarizing key impacts and risks across sectors and regions, and were introduced in the IPCC Third Assessment Report. RFCs illustrate the implications of global warming for people, economies and ecosystems. Impacts and/or risks for each RFC are based on assessment of the new literature that has appeared. As in AR5, this literature was used to make expert judgments to assess the levels of global warming at which levels of impact and/or risk are undetectable, moderate, high or very high. The selection of impacts and risks to natural, managed and human systems in the lower panel is illustrative and is not intended to be fully comprehensive. {3.4, 3.5, 3.5.2.1, 3.5.2.2, 3.5.2.3, 3.5.2.4, 3.5.2.5, 5.4.1, 5.5.3, 5.6.1, Box 3.4}

RFC1 Unique and threatened systems: ecological and human systems that have restricted geographic ranges constrained by climate-related conditions and have high endemism or other distinctive properties. Examples include coral reefs, the Arctic and its indigenous people, mountain glaciers and biodiversity hotspots.

RFC2 Extreme weather events: risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events such as heat waves, heavy rain, drought and associated wildfires, and coastal flooding.

RFC3 Distribution of impacts: risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability.

RFC4 Global aggregate impacts: global monetary damage, global-scale degradation and loss of ecosystems and biodiversity.

RFC5 Large-scale singular events: are relatively large, abrupt and sometimes irreversible changes in systems that are caused by global warming. Examples include disintegration of the Greenland and Antarctic ice sheets.

C. Emission Pathways and System Transitions Consistent with 1.5°C Global Warming

C.1 In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO_2 emissions decline by about 45% from 2010 levels by 2030 (40–60% interquartile range), reaching net zero around 2050 (2045–2055 interquartile range). For limiting global warming to below 2°C[11] CO_2 emissions are projected to decline by about 25% by 2030 in most pathways (10–30% interquartile range) and reach net zero around 2070 (2065–2080 interquartile range). Non-CO_2 emissions in pathways that limit global warming to 1.5°C show deep reductions that are similar to those in pathways limiting warming to 2°C. (*high confidence*) (Figure SPM.3a) {2.1, 2.3, Table 2.4}

C.1.1 CO_2 emissions reductions that limit global warming to 1.5°C with no or limited overshoot can involve different portfolios of mitigation measures, striking different balances between lowering energy and resource intensity, rate of decarbonization, and the reliance on carbon dioxide removal. Different portfolios face different implementation challenges and potential synergies and trade-offs with sustainable development. (*high confidence*) (Figure SPM.3b) {2.3.2, 2.3.4, 2.4, 2.5.3}

C.1.2 Modelled pathways that limit global warming to 1.5°C with no or limited overshoot involve deep reductions in emissions of methane and black carbon (35% or more of both by 2050 relative to 2010). These pathways also reduce most of the cooling aerosols, which partially offsets mitigation effects for two to three decades. Non-CO_2 emissions[12] can be reduced as a result of broad mitigation measures in the energy sector. In addition, targeted non-CO_2 mitigation measures can reduce nitrous oxide and methane from agriculture, methane from the waste sector, some sources of black carbon, and hydrofluorocarbons. High bioenergy demand can increase emissions of nitrous oxide in some 1.5°C pathways, highlighting the importance of appropriate management approaches. Improved air quality resulting from projected reductions in many non-CO_2 emissions provide direct and immediate population health benefits in all 1.5°C model pathways. (*high confidence*) (Figure SPM.3a) {2.2.1, 2.3.3, 2.4.4, 2.5.3, 4.3.6, 5.4.2}

C.1.3 Limiting global warming requires limiting the total cumulative global anthropogenic emissions of CO_2 since the pre-industrial period, that is, staying within a total carbon budget (*high confidence*).[13] By the end of 2017, anthropogenic CO_2 emissions since the pre-industrial period are estimated to have reduced the total carbon budget for 1.5°C by approximately 2200 ± 320 $GtCO_2$ (*medium confidence*). The associated remaining budget is being depleted by current emissions of 42 ± 3 $GtCO_2$ per year (*high confidence*). The choice of the measure of global temperature affects the estimated remaining carbon budget. Using global mean surface air temperature, as in AR5, gives an estimate of the remaining carbon budget of 580 $GtCO_2$ for a 50% probability of limiting warming to 1.5°C, and 420 $GtCO_2$ for a 66% probability (*medium confidence*).[14] Alternatively, using GMST gives estimates of 770 and 570 $GtCO_2$, for 50% and 66% probabilities,[15] respectively (*medium confidence*). Uncertainties in the size of these estimated remaining carbon budgets are substantial and depend on several factors. Uncertainties in the climate response to CO_2 and non-CO_2 emissions contribute ±400 $GtCO_2$ and the level of historic warming contributes ±250 $GtCO_2$ (*medium confidence*). Potential additional carbon release from future permafrost thawing and methane release from wetlands would reduce budgets by up to 100 $GtCO_2$ over the course of this century and more thereafter (*medium confidence*). In addition, the level of non-CO_2 mitigation in the future could alter the remaining carbon budget by 250 $GtCO_2$ in either direction (*medium confidence*). {1.2.4, 2.2.2, 2.6.1, Table 2.2, Chapter 2 Supplementary Material}

C.1.4 Solar radiation modification (SRM) measures are not included in any of the available assessed pathways. Although some SRM measures may be theoretically effective in reducing an overshoot, they face large uncertainties and knowledge gaps

11 References to pathways limiting global warming to 2°C are based on a 66% probability of staying below 2°C.

12 Non-CO_2 emissions included in this Report are all anthropogenic emissions other than CO_2 that result in radiative forcing. These include short-lived climate forcers, such as methane, some fluorinated gases, ozone precursors, aerosols or aerosol precursors, such as black carbon and sulphur dioxide, respectively, as well as long-lived greenhouse gases, such as nitrous oxide or some fluorinated gases. The radiative forcing associated with non-CO_2 emissions and changes in surface albedo is referred to as non-CO_2 radiative forcing. {2.2.1}

13 There is a clear scientific basis for a total carbon budget consistent with limiting global warming to 1.5°C. However, neither this total carbon budget nor the fraction of this budget taken up by past emissions were assessed in this Report.

14 Irrespective of the measure of global temperature used, updated understanding and further advances in methods have led to an increase in the estimated remaining carbon budget of about 300 $GtCO_2$ compared to AR5. (*medium confidence*) {2.2.2}

15 These estimates use observed GMST to 2006–2015 and estimate future temperature changes using near surface air temperatures.

as well as substantial risks and institutional and social constraints to deployment related to governance, ethics, and impacts on sustainable development. They also do not mitigate ocean acidification. (*medium confidence*) {4.3.8, Cross-Chapter Box 10 in Chapter 4}

Global emissions pathway characteristics

General characteristics of the evolution of anthropogenic net emissions of CO_2, and total emissions of methane, black carbon, and nitrous oxide in model pathways that limit global warming to 1.5°C with no or limited overshoot. Net emissions are defined as anthropogenic emissions reduced by anthropogenic removals. Reductions in net emissions can be achieved through different portfolios of mitigation measures illustrated in Figure SPM.3b.

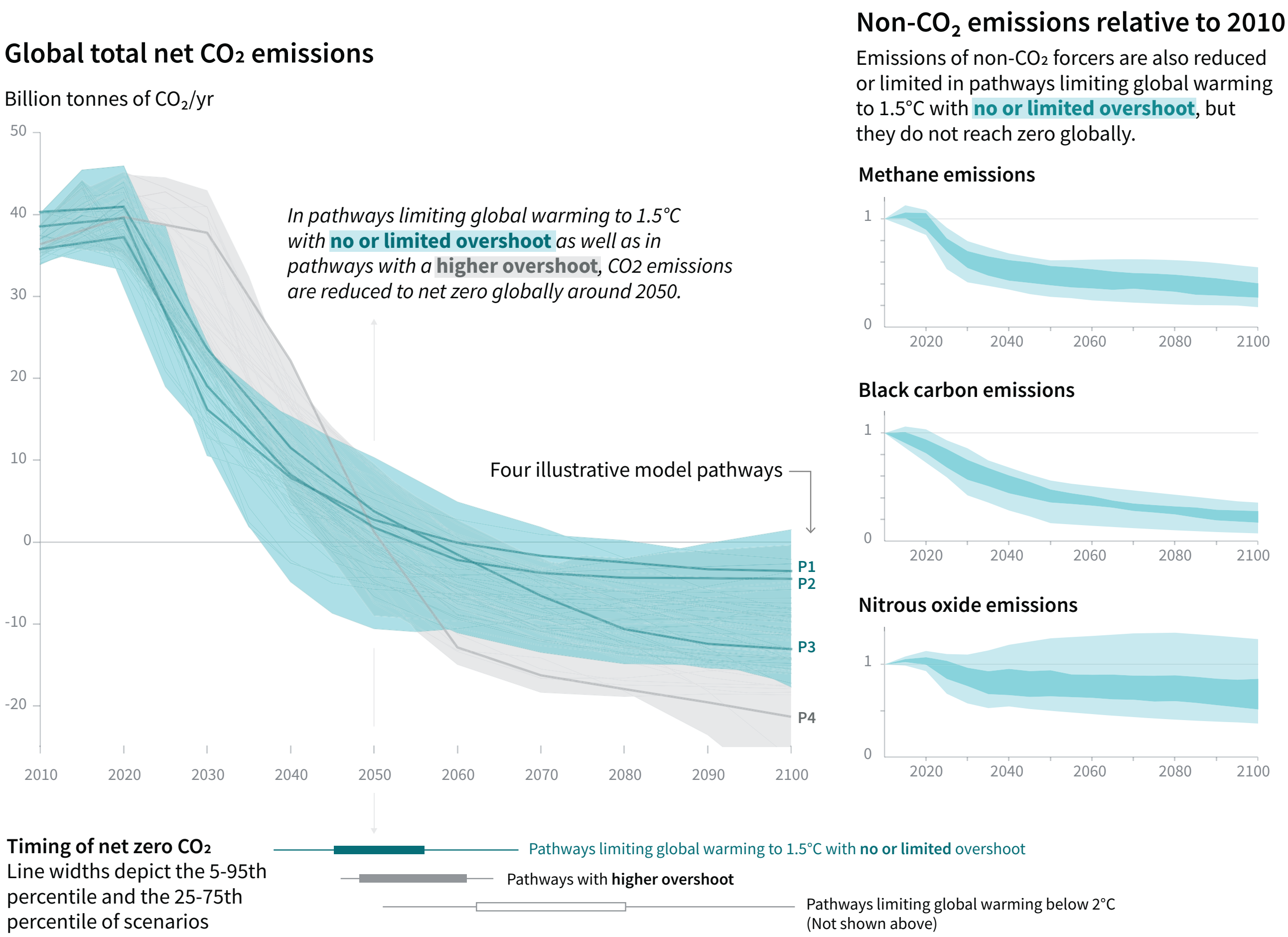


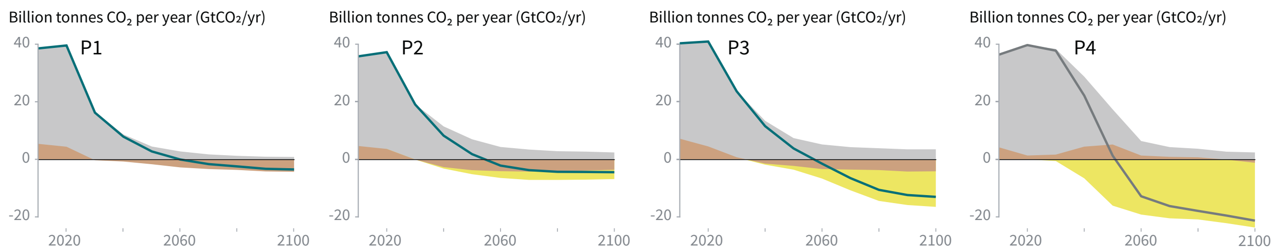
Figure SPM.3a | Global emissions pathway characteristics. The main panel shows global net anthropogenic CO_2 emissions in pathways limiting global warming to 1.5°C with no or limited (less than 0.1°C) overshoot and pathways with higher overshoot. The shaded area shows the full range for pathways analysed in this Report. The panels on the right show non-CO_2 emissions ranges for three compounds with large historical forcing and a substantial portion of emissions coming from sources distinct from those central to CO_2 mitigation. Shaded areas in these panels show the 5–95% (light shading) and interquartile (dark shading) ranges of pathways limiting global warming to 1.5°C with no or limited overshoot. Box and whiskers at the bottom of the figure show the timing of pathways reaching global net zero CO_2 emission levels, and a comparison with pathways limiting global warming to 2°C with at least 66% probability. Four illustrative model pathways are highlighted in the main panel and are labelled P1, P2, P3 and P4, corresponding to the LED, S1, S2, and S5 pathways assessed in Chapter 2. Descriptions and characteristics of these pathways are available in Figure SPM.3b. {2.1, 2.2, 2.3, Figure 2.5, Figure 2.10, Figure 2.11}

Characteristics of four illustrative model pathways

Different mitigation strategies can achieve the net emissions reductions that would be required to follow a pathway that limits global warming to 1.5°C with no or limited overshoot. All pathways use Carbon Dioxide Removal (CDR), but the amount varies across pathways, as do the relative contributions of Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector. This has implications for emissions and several other pathway characteristics.

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways

Fossil fuel and industry AFOLU BECCS



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Global indicators	P1	P2	P3	P4	**Interquartile range**
Pathway classification	No or limited overshoot	No or limited overshoot	No or limited overshoot	Higher overshoot	No or limited overshoot
CO_2 emission change in 2030 (% rel to 2010)	-58	-47	-41	4	(-58,-40)
└ in 2050 (% rel to 2010)	-93	-95	-91	-97	(-107,-94)
Kyoto-GHG emissions in 2030 (% rel to 2010)*	-50	-49	-35	-2	(-51,-39)
└ in 2050 (% rel to 2010)	-82	-89	-78	-80	(-93,-81)
*Final energy demand** in 2030 (% rel to 2010)*	-15	-5	17	39	(-12,7)
└ in 2050 (% rel to 2010)	-32	2	21	44	(-11,22)
Renewable share in electricity in 2030 (%)	60	58	48	25	(47,65)
└ in 2050 (%)	77	81	63	70	(69,86)
Primary energy from coal in 2030 (% rel to 2010)	-78	-61	-75	-59	(-78, -59)
└ in 2050 (% rel to 2010)	-97	-77	-73	-97	(-95, -74)
from oil in 2030 (% rel to 2010)	-37	-13	-3	86	(-34,3)
└ in 2050 (% rel to 2010)	-87	-50	-81	-32	(-78,-31)
from gas in 2030 (% rel to 2010)	-25	-20	33	37	(-26,21)
└ in 2050 (% rel to 2010)	-74	-53	21	-48	(-56,6)
from nuclear in 2030 (% rel to 2010)	59	83	98	106	(44,102)
└ in 2050 (% rel to 2010)	150	98	501	468	(91,190)
from biomass in 2030 (% rel to 2010)	-11	0	36	-1	(29,80)
└ in 2050 (% rel to 2010)	-16	49	121	418	(123,261)
from non-biomass renewables in 2030 (% rel to 2010)	430	470	315	110	(245,436)
└ in 2050 (% rel to 2010)	833	1327	878	1137	(576,1299)
Cumulative CCS until 2100 ($GtCO_2$)	0	348	687	1218	(550,1017)
└ of which BECCS ($GtCO_2$)	0	151	414	1191	(364,662)
Land area of bioenergy crops in 2050 (million km^2)	0.2	0.9	2.8	7.2	(1.5,3.2)
Agricultural CH_4 emissions in 2030 (% rel to 2010)	-24	-48	1	14	(-30,-11)
in 2050 (% rel to 2010)	-33	-69	-23	2	(-47,-24)
Agricultural N_2O emissions in 2030 (% rel to 2010)	5	-26	15	3	(-21,3)
in 2050 (% rel to 2010)	6	-26	0	39	(-26,1)

NOTE: Indicators have been selected to show global trends identified by the Chapter 2 assessment. National and sectoral characteristics can differ substantially from the global trends shown above.

** Kyoto-gas emissions are based on IPCC Second Assessment Report GWP-100*
*** Changes in energy demand are associated with improvements in energy efficiency and behaviour change*

Figure SPM.3b | Characteristics of four illustrative model pathways in relation to global warming of 1.5°C introduced in Figure SPM.3a. These pathways were selected to show a range of potential mitigation approaches and vary widely in their projected energy and land use, as well as their assumptions about future socio-economic developments, including economic and population growth, equity and sustainability. A breakdown of the global net anthropogenic CO_2 emissions into the contributions in terms of CO_2 emissions from fossil fuel and industry; agriculture, forestry and other land use (AFOLU); and bioenergy with carbon capture and storage (BECCS) is shown. AFOLU estimates reported here are not necessarily comparable with countries' estimates. Further characteristics for each of these pathways are listed below each pathway. These pathways illustrate relative global differences in mitigation strategies, but do not represent central estimates, national strategies, and do not indicate requirements. For comparison, the right-most column shows the interquartile ranges across pathways with no or limited overshoot of 1.5°C. Pathways P1, P2, P3 and P4 correspond to the LED, S1, S2 and S5 pathways assessed in Chapter 2 (Figure SPM.3a). {2.2.1, 2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.4.1, 2.4.2, 2.4.4, 2.5.3, Figure 2.5, Figure 2.6, Figure 2.9, Figure 2.10, Figure 2.11, Figure 2.14, Figure 2.15, Figure 2.16, Figure 2.17, Figure 2.24, Figure 2.25, Table 2.4, Table 2.6, Table 2.7, Table 2.9, Table 4.1}

C.2 Pathways limiting global warming to 1.5°C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems (*high confidence*). These systems transitions are unprecedented in terms of scale, but not necessarily in terms of speed, and imply deep emissions reductions in all sectors, a wide portfolio of mitigation options and a significant upscaling of investments in those options (*medium confidence*). {2.3, 2.4, 2.5, 4.2, 4.3, 4.4, 4.5}

C.2.1 Pathways that limit global warming to 1.5°C with no or limited overshoot show system changes that are more rapid and pronounced over the next two decades than in 2°C pathways (*high confidence*). The rates of system changes associated with limiting global warming to 1.5°C with no or limited overshoot have occurred in the past within specific sectors, technologies and spatial contexts, but there is no documented historic precedent for their scale (*medium confidence*). {2.3.3, 2.3.4, 2.4, 2.5, 4.2.1, 4.2.2, Cross-Chapter Box 11 in Chapter 4}

C.2.2 In energy systems, modelled global pathways (considered in the literature) limiting global warming to 1.5°C with no or limited overshoot (for more details see Figure SPM.3b) generally meet energy service demand with lower energy use, including through enhanced energy efficiency, and show faster electrification of energy end use compared to 2°C (*high confidence*). In 1.5°C pathways with no or limited overshoot, low-emission energy sources are projected to have a higher share, compared with 2°C pathways, particularly before 2050 (*high confidence*). In 1.5°C pathways with no or limited overshoot, renewables are projected to supply 70–85% (interquartile range) of electricity in 2050 (*high confidence*). In electricity generation, shares of nuclear and fossil fuels with carbon dioxide capture and storage (CCS) are modelled to increase in most 1.5°C pathways with no or limited overshoot. In modelled 1.5°C pathways with limited or no overshoot, the use of CCS would allow the electricity generation share of gas to be approximately 8% (3–11% interquartile range) of global electricity in 2050, while the use of coal shows a steep reduction in all pathways and would be reduced to close to 0% (0–2% interquartile range) of electricity (*high confidence*). While acknowledging the challenges, and differences between the options and national circumstances, political, economic, social and technical feasibility of solar energy, wind energy and electricity storage technologies have substantially improved over the past few years (*high confidence*). These improvements signal a potential system transition in electricity generation. (Figure SPM.3b) {2.4.1, 2.4.2, Figure 2.1, Table 2.6, Table 2.7, Cross-Chapter Box 6 in Chapter 3, 4.2.1, 4.3.1, 4.3.3, 4.5.2}

C.2.3 CO_2 emissions from industry in pathways limiting global warming to 1.5°C with no or limited overshoot are projected to be about 65–90% (interquartile range) lower in 2050 relative to 2010, as compared to 50–80% for global warming of 2°C (*medium confidence*). Such reductions can be achieved through combinations of new and existing technologies and practices, including electrification, hydrogen, sustainable bio-based feedstocks, product substitution, and carbon capture, utilization and storage (CCUS). These options are technically proven at various scales but their large-scale deployment may be limited by economic, financial, human capacity and institutional constraints in specific contexts, and specific characteristics of large-scale industrial installations. In industry, emissions reductions by energy and process efficiency by themselves are insufficient for limiting warming to 1.5°C with no or limited overshoot (*high confidence*). {2.4.3, 4.2.1, Table 4.1, Table 4.3, 4.3.3, 4.3.4, 4.5.2}

C.2.4 The urban and infrastructure system transition consistent with limiting global warming to 1.5°C with no or limited overshoot would imply, for example, changes in land and urban planning practices, as well as deeper emissions reductions in transport and buildings compared to pathways that limit global warming below 2°C (*medium confidence*). Technical measures

and practices enabling deep emissions reductions include various energy efficiency options. In pathways limiting global warming to 1.5°C with no or limited overshoot, the electricity share of energy demand in buildings would be about 55–75% in 2050 compared to 50–70% in 2050 for 2°C global warming (*medium confidence*). In the transport sector, the share of low-emission final energy would rise from less than 5% in 2020 to about 35–65% in 2050 compared to 25–45% for 2°C of global warming (*medium confidence*). Economic, institutional and socio-cultural barriers may inhibit these urban and infrastructure system transitions, depending on national, regional and local circumstances, capabilities and the availability of capital (*high confidence*). {2.3.4, 2.4.3, 4.2.1, Table 4.1, 4.3.3, 4.5.2}

C.2.5 Transitions in global and regional land use are found in all pathways limiting global warming to 1.5°C with no or limited overshoot, but their scale depends on the pursued mitigation portfolio. Model pathways that limit global warming to 1.5°C with no or limited overshoot project a 4 million km^2 reduction to a 2.5 million km^2 increase of non-pasture agricultural land for food and feed crops and a 0.5–11 million km^2 reduction of pasture land, to be converted into a 0–6 million km^2 increase of agricultural land for energy crops and a 2 million km^2 reduction to 9.5 million km^2 increase in forests by 2050 relative to 2010 (*medium confidence*).[16] Land-use transitions of similar magnitude can be observed in modelled 2°C pathways (*medium confidence*). Such large transitions pose profound challenges for sustainable management of the various demands on land for human settlements, food, livestock feed, fibre, bioenergy, carbon storage, biodiversity and other ecosystem services (*high confidence*). Mitigation options limiting the demand for land include sustainable intensification of land-use practices, ecosystem restoration and changes towards less resource-intensive diets (*high confidence*). The implementation of land-based mitigation options would require overcoming socio-economic, institutional, technological, financing and environmental barriers that differ across regions (*high confidence*). {2.4.4, Figure 2.24, 4.3.2, 4.3.7, 4.5.2, Cross-Chapter Box 7 in Chapter 3}

C.2.6 Additional annual average energy-related investments for the period 2016 to 2050 in pathways limiting warming to 1.5°C compared to pathways without new climate policies beyond those in place today are estimated to be around 830 billion USD2010 (range of 150 billion to 1700 billion USD2010 across six models[17]). This compares to total annual average energy supply investments in 1.5°C pathways of 1460 to 3510 billion USD2010 and total annual average energy demand investments of 640 to 910 billion USD2010 for the period 2016 to 2050. Total energy-related investments increase by about 12% (range of 3% to 24%) in 1.5°C pathways relative to 2°C pathways. Annual investments in low-carbon energy technologies and energy efficiency are upscaled by roughly a factor of six (range of factor of 4 to 10) by 2050 compared to 2015 (*medium confidence*). {2.5.2, Box 4.8, Figure 2.27}

C.2.7 Modelled pathways limiting global warming to 1.5°C with no or limited overshoot project a wide range of global average discounted marginal abatement costs over the 21st century. They are roughly 3-4 times higher than in pathways limiting global warming to below 2°C (*high confidence*). The economic literature distinguishes marginal abatement costs from total mitigation costs in the economy. The literature on total mitigation costs of 1.5°C mitigation pathways is limited and was not assessed in this Report. Knowledge gaps remain in the integrated assessment of the economy-wide costs and benefits of mitigation in line with pathways limiting warming to 1.5°C. {2.5.2; 2.6; Figure 2.26}

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16 The projected land-use changes presented are not deployed to their upper limits simultaneously in a single pathway.

17 Including two pathways limiting warming to 1.5°C with no or limited overshoot and four pathways with higher overshoot.

C.3 All pathways that limit global warming to 1.5°C with limited or no overshoot project the use of carbon dioxide removal (CDR) on the order of 100–1000 $GtCO_2$ over the 21st century. CDR would be used to compensate for residual emissions and, in most cases, achieve net negative emissions to return global warming to 1.5°C following a peak (*high confidence*). CDR deployment of several hundreds of $GtCO_2$ is subject to multiple feasibility and sustainability constraints (*high confidence*). Significant near-term emissions reductions and measures to lower energy and land demand can limit CDR deployment to a few hundred $GtCO_2$ without reliance on bioenergy with carbon capture and storage (BECCS) (*high confidence*). {2.3, 2.4, 3.6.2, 4.3, 5.4}

C.3.1 Existing and potential CDR measures include afforestation and reforestation, land restoration and soil carbon sequestration, BECCS, direct air carbon capture and storage (DACCS), enhanced weathering and ocean alkalinization. These differ widely in terms of maturity, potentials, costs, risks, co-benefits and trade-offs (*high confidence*). To date, only a few published pathways include CDR measures other than afforestation and BECCS. {2.3.4, 3.6.2, 4.3.2, 4.3.7}

C.3.2 In pathways limiting global warming to 1.5°C with limited or no overshoot, BECCS deployment is projected to range from 0–1, 0–8, and 0–16 $GtCO_2$ yr^{-1} in 2030, 2050, and 2100, respectively, while agriculture, forestry and land-use (AFOLU) related CDR measures are projected to remove 0–5, 1–11, and 1–5 $GtCO_2$ yr^{-1} in these years (*medium confidence*). The upper end of these deployment ranges by mid-century exceeds the BECCS potential of up to 5 $GtCO_2$ yr^{-1} and afforestation potential of up to 3.6 $GtCO_2$ yr^{-1} assessed based on recent literature (*medium confidence*). Some pathways avoid BECCS deployment completely through demand-side measures and greater reliance on AFOLU-related CDR measures (*medium confidence*). The use of bioenergy can be as high or even higher when BECCS is excluded compared to when it is included due to its potential for replacing fossil fuels across sectors (*high confidence*). (Figure SPM.3b) {2.3.3, 2.3.4, 2.4.2, 3.6.2, 4.3.1, 4.2.3, 4.3.2, 4.3.7, 4.4.3, Table 2.4}

C.3.3 Pathways that overshoot 1.5°C of global warming rely on CDR exceeding residual CO_2 emissions later in the century to return to below 1.5°C by 2100, with larger overshoots requiring greater amounts of CDR (Figure SPM.3b) (*high confidence*). Limitations on the speed, scale, and societal acceptability of CDR deployment hence determine the ability to return global warming to below 1.5°C following an overshoot. Carbon cycle and climate system understanding is still limited about the effectiveness of net negative emissions to reduce temperatures after they peak (*high confidence*). {2.2, 2.3.4, 2.3.5, 2.6, 4.3.7, 4.5.2, Table 4.11}

C.3.4 Most current and potential CDR measures could have significant impacts on land, energy, water or nutrients if deployed at large scale (*high confidence*). Afforestation and bioenergy may compete with other land uses and may have significant impacts on agricultural and food systems, biodiversity, and other ecosystem functions and services (*high confidence*). Effective governance is needed to limit such trade-offs and ensure permanence of carbon removal in terrestrial, geological and ocean reservoirs (*high confidence*). Feasibility and sustainability of CDR use could be enhanced by a portfolio of options deployed at substantial, but lesser scales, rather than a single option at very large scale (*high confidence*). (Figure SPM.3b) {2.3.4, 2.4.4, 2.5.3, 2.6, 3.6.2, 4.3.2, 4.3.7, 4.5.2, 5.4.1, 5.4.2; Cross-Chapter Boxes 7 and 8 in Chapter 3, Table 4.11, Table 5.3, Figure 5.3}

C.3.5 Some AFOLU-related CDR measures such as restoration of natural ecosystems and soil carbon sequestration could provide co-benefits such as improved biodiversity, soil quality, and local food security. If deployed at large scale, they would require governance systems enabling sustainable land management to conserve and protect land carbon stocks and other ecosystem functions and services (*medium confidence*). (Figure SPM.4) {2.3.3, 2.3.4, 2.4.2, 2.4.4, 3.6.2, 5.4.1, Cross-Chapter Boxes 3 in Chapter 1 and 7 in Chapter 3, 4.3.2, 4.3.7, 4.4.1, 4.5.2, Table 2.4}

D. Strengthening the Global Response in the Context of Sustainable Development and Efforts to Eradicate Poverty

D.1 Estimates of the global emissions outcome of current nationally stated mitigation ambitions as submitted under the Paris Agreement would lead to global greenhouse gas emissions[18] in 2030 of 52–58 $GtCO_2eq\ yr^{-1}$ (*medium confidence*). Pathways reflecting these ambitions would not limit global warming to 1.5°C, even if supplemented by very challenging increases in the scale and ambition of emissions reductions after 2030 (*high confidence*). Avoiding overshoot and reliance on future large-scale deployment of carbon dioxide removal (CDR) can only be achieved if global CO_2 emissions start to decline well before 2030 (*high confidence*). {1.2, 2.3, 3.3, 3.4, 4.2, 4.4, Cross-Chapter Box 11 in Chapter 4}

D.1.1 Pathways that limit global warming to 1.5°C with no or limited overshoot show clear emission reductions by 2030 (*high confidence*). All but one show a decline in global greenhouse gas emissions to below 35 $GtCO_2eq\ yr^{-1}$ in 2030, and half of available pathways fall within the 25–30 $GtCO_2eq\ yr^{-1}$ range (interquartile range), a 40–50% reduction from 2010 levels (*high confidence*). Pathways reflecting current nationally stated mitigation ambition until 2030 are broadly consistent with cost-effective pathways that result in a global warming of about 3°C by 2100, with warming continuing afterwards (*medium confidence*). {2.3.3, 2.3.5, Cross-Chapter Box 11 in Chapter 4, 5.5.3.2}

D.1.2 Overshoot trajectories result in higher impacts and associated challenges compared to pathways that limit global warming to 1.5°C with no or limited overshoot (*high confidence*). Reversing warming after an overshoot of 0.2°C or larger during this century would require upscaling and deployment of CDR at rates and volumes that might not be achievable given considerable implementation challenges (*medium confidence*). {1.3.3, 2.3.4, 2.3.5, 2.5.1, 3.3, 4.3.7, Cross-Chapter Box 8 in Chapter 3, Cross-Chapter Box 11 in Chapter 4}

D.1.3 The lower the emissions in 2030, the lower the challenge in limiting global warming to 1.5°C after 2030 with no or limited overshoot (*high confidence*). The challenges from delayed actions to reduce greenhouse gas emissions include the risk of cost escalation, lock-in in carbon-emitting infrastructure, stranded assets, and reduced flexibility in future response options in the medium to long term (*high confidence*). These may increase uneven distributional impacts between countries at different stages of development (*medium confidence*). {2.3.5, 4.4.5, 5.4.2}

D.2 The avoided climate change impacts on sustainable development, eradication of poverty and reducing inequalities would be greater if global warming were limited to 1.5°C rather than 2°C, if mitigation and adaptation synergies are maximized while trade-offs are minimized (*high confidence*). {1.1, 1.4, 2.5, 3.3, 3.4, 5.2, Table 5.1}

D.2.1 Climate change impacts and responses are closely linked to sustainable development which balances social well-being, economic prosperity and environmental protection. The United Nations Sustainable Development Goals (SDGs), adopted in 2015, provide an established framework for assessing the links between global warming of 1.5°C or 2°C and development goals that include poverty eradication, reducing inequalities, and climate action. (*high confidence*) {Cross-Chapter Box 4 in Chapter 1, 1.4, 5.1}

D.2.2 The consideration of ethics and equity can help address the uneven distribution of adverse impacts associated with 1.5°C and higher levels of global warming, as well as those from mitigation and adaptation, particularly for poor and disadvantaged populations, in all societies (*high confidence*). {1.1.1, 1.1.2, 1.4.3, 2.5.3, 3.4.10, 5.1, 5.2, 5.3. 5.4, Cross-Chapter Box 4 in Chapter 1, Cross-Chapter Boxes 6 and 8 in Chapter 3, and Cross-Chapter Box 12 in Chapter 5}

D.2.3 Mitigation and adaptation consistent with limiting global warming to 1.5°C are underpinned by enabling conditions, assessed in this Report across the geophysical, environmental-ecological, technological, economic, socio-cultural and institutional

18 GHG emissions have been aggregated with 100-year GWP values as introduced in the IPCC Second Assessment Report.

dimensions of feasibility. Strengthened multilevel governance, institutional capacity, policy instruments, technological innovation and transfer and mobilization of finance, and changes in human behaviour and lifestyles are enabling conditions that enhance the feasibility of mitigation and adaptation options for 1.5°C-consistent systems transitions. (*high confidence*) {1.4, Cross-Chapter Box 3 in Chapter 1, 2.5.1, 4.4, 4.5, 5.6}

D.3 Adaptation options specific to national contexts, if carefully selected together with enabling conditions, will have benefits for sustainable development and poverty reduction with global warming of 1.5°C, although trade-offs are possible (*high confidence*). {1.4, 4.3, 4.5}

D.3.1 Adaptation options that reduce the vulnerability of human and natural systems have many synergies with sustainable development, if well managed, such as ensuring food and water security, reducing disaster risks, improving health conditions, maintaining ecosystem services and reducing poverty and inequality (*high confidence*). Increasing investment in physical and social infrastructure is a key enabling condition to enhance the resilience and the adaptive capacities of societies. These benefits can occur in most regions with adaptation to 1.5°C of global warming (*high confidence*). {1.4.3, 4.2.2, 4.3.1, 4.3.2, 4.3.3, 4.3.5, 4.4.1, 4.4.3, 4.5.3, 5.3.1, 5.3.2}

D.3.2 Adaptation to 1.5°C global warming can also result in trade-offs or maladaptations with adverse impacts for sustainable development. For example, if poorly designed or implemented, adaptation projects in a range of sectors can increase greenhouse gas emissions and water use, increase gender and social inequality, undermine health conditions, and encroach on natural ecosystems (*high confidence*). These trade-offs can be reduced by adaptations that include attention to poverty and sustainable development (*high confidence*). {4.3.2, 4.3.3, 4.5.4, 5.3.2; Cross-Chapter Boxes 6 and 7 in Chapter 3}

D.3.3 A mix of adaptation and mitigation options to limit global warming to 1.5°C, implemented in a participatory and integrated manner, can enable rapid, systemic transitions in urban and rural areas (*high confidence*). These are most effective when aligned with economic and sustainable development, and when local and regional governments and decision makers are supported by national governments (*medium confidence*). {4.3.2, 4.3.3, 4.4.1, 4.4.2}

D.3.4 Adaptation options that also mitigate emissions can provide synergies and cost savings in most sectors and system transitions, such as when land management reduces emissions and disaster risk, or when low-carbon buildings are also designed for efficient cooling. Trade-offs between mitigation and adaptation, when limiting global warming to 1.5°C, such as when bioenergy crops, reforestation or afforestation encroach on land needed for agricultural adaptation, can undermine food security, livelihoods, ecosystem functions and services and other aspects of sustainable development. (*high confidence*) {3.4.3, 4.3.2, 4.3.4, 4.4.1, 4.5.2, 4.5.3, 4.5.4}

D.4 Mitigation options consistent with 1.5°C pathways are associated with multiple synergies and trade-offs across the Sustainable Development Goals (SDGs). While the total number of possible synergies exceeds the number of trade-offs, their net effect will depend on the pace and magnitude of changes, the composition of the mitigation portfolio and the management of the transition. (*high confidence*) (Figure SPM.4) {2.5, 4.5, 5.4}

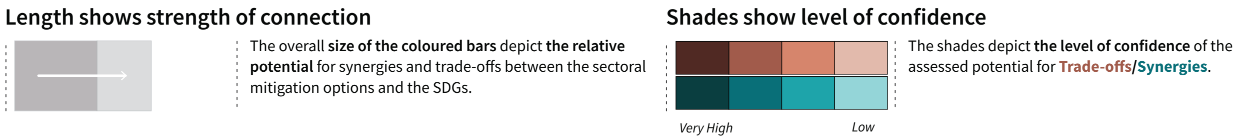
D.4.1 1.5°C pathways have robust synergies particularly for the SDGs 3 (health), 7 (clean energy), 11 (cities and communities), 12 (responsible consumption and production) and 14 (oceans) (*very high confidence*). Some 1.5°C pathways show potential trade-offs with mitigation for SDGs 1 (poverty), 2 (hunger), 6 (water) and 7 (energy access), if not managed carefully (*high confidence*). (Figure SPM.4) {5.4.2; Figure 5.4, Cross-Chapter Boxes 7 and 8 in Chapter 3}

D.4.2 1.5°C pathways that include low energy demand (e.g., see P1 in Figure SPM.3a and SPM.3b), low material consumption, and low GHG-intensive food consumption have the most pronounced synergies and the lowest number of trade-offs with respect to sustainable development and the SDGs (*high confidence*). Such pathways would reduce dependence on CDR. In modelled pathways, sustainable development, eradicating poverty and reducing inequality can support limiting warming to 1.5°C (*high confidence*). (Figure SPM.3b, Figure SPM.4) {2.4.3, 2.5.1, 2.5.3, Figure 2.4, Figure 2.28, 5.4.1, 5.4.2, Figure 5.4}

SPM

Indicative linkages between mitigation options and sustainable development using SDGs (The linkages do not show costs and benefits)

Mitigation options deployed in each sector can be associated with potential positive effects (synergies) or negative effects (trade-offs) with the Sustainable Development Goals (SDGs). The degree to which this potential is realized will depend on the selected portfolio of mitigation options, mitigation policy design, and local circumstances and context. Particularly in the energy-demand sector, the potential for synergies is larger than for trade-offs. The bars group individually assessed options by level of confidence and take into account the relative strength of the assessed mitigation-SDG connections.



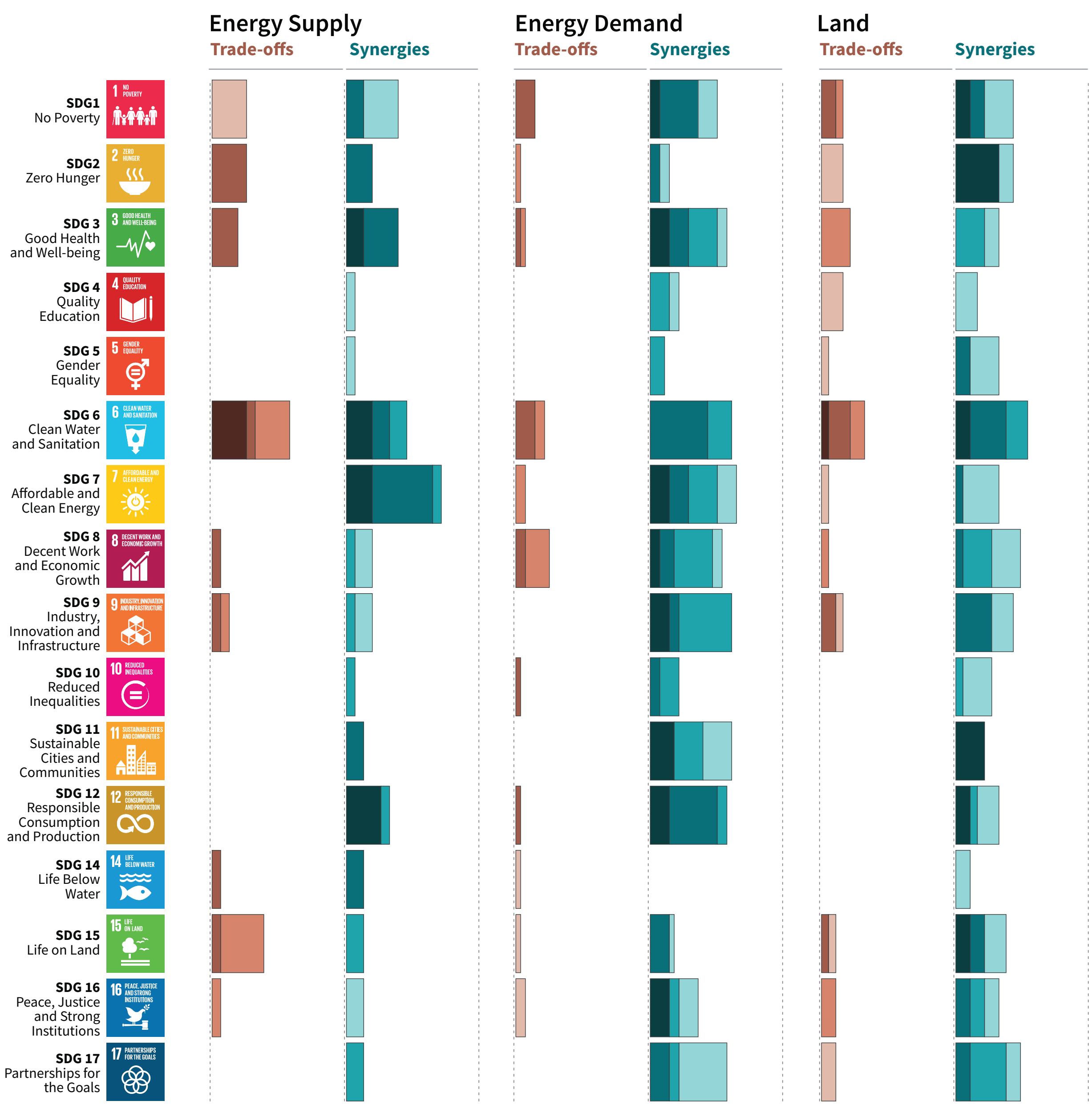


Figure SPM.4 | Potential synergies and trade-offs between the sectoral portfolio of climate change mitigation options and the Sustainable Development Goals (SDGs). The SDGs serve as an analytical framework for the assessment of the different sustainable development dimensions, which extend beyond the time frame of the 2030 SDG targets. The assessment is based on literature on mitigation options that are considered relevant for 1.5°C. The assessed strength of the SDG interactions is based on the qualitative and quantitative assessment of individual mitigation options listed in Table 5.2. For each mitigation option, the strength of the SDG-connection as well as the associated confidence of the underlying literature (shades of green and red) was assessed. The strength of positive connections (synergies) and negative connections (trade-offs) across all individual options within a sector (see Table 5.2) are aggregated into sectoral potentials for the whole mitigation portfolio. The (white) areas outside the bars, which indicate no interactions, have *low confidence* due to the uncertainty and limited number of studies exploring indirect effects. The strength of the connection considers only the effect of mitigation and does not include benefits of avoided impacts. SDG 13 (climate action) is not listed because mitigation is being considered in terms of interactions with SDGs and not vice versa. The bars denote the strength of the connection, and do not consider the strength of the impact on the SDGs. The energy demand sector comprises behavioural responses, fuel switching and efficiency options in the transport, industry and building sector as well as carbon capture options in the industry sector. Options assessed in the energy supply sector comprise biomass and non-biomass renewables, nuclear, carbon capture and storage (CCS) with bioenergy, and CCS with fossil fuels. Options in the land sector comprise agricultural and forest options, sustainable diets and reduced food waste, soil sequestration, livestock and manure management, reduced deforestation, afforestation and reforestation, and responsible sourcing. In addition to this figure, options in the ocean sector are discussed in the underlying report. {5.4, Table 5.2, Figure 5.2}

Information about the net impacts of mitigation on sustainable development in 1.5°C pathways is available only for a limited number of SDGs and mitigation options. Only a limited number of studies have assessed the benefits of avoided climate change impacts of 1.5°C pathways for the SDGs, and the co-effects of adaptation for mitigation and the SDGs. The assessment of the indicative mitigation potentials in Figure SPM.4 is a step further from AR5 towards a more comprehensive and integrated assessment in the future.

D.4.3 1.5°C and 2°C modelled pathways often rely on the deployment of large-scale land-related measures like afforestation and bioenergy supply, which, if poorly managed, can compete with food production and hence raise food security concerns (*high confidence*). The impacts of carbon dioxide removal (CDR) options on SDGs depend on the type of options and the scale of deployment (*high confidence*). If poorly implemented, CDR options such as BECCS and AFOLU options would lead to trade-offs. Context-relevant design and implementation requires considering people's needs, biodiversity, and other sustainable development dimensions (*very high confidence*). (Figure SPM.4) {5.4.1.3, Cross-Chapter Box 7 in Chapter 3}

D.4.4 Mitigation consistent with 1.5°C pathways creates risks for sustainable development in regions with high dependency on fossil fuels for revenue and employment generation (*high confidence*). Policies that promote diversification of the economy and the energy sector can address the associated challenges (*high confidence*). {5.4.1.2, Box 5.2}

D.4.5 Redistributive policies across sectors and populations that shield the poor and vulnerable can resolve trade-offs for a range of SDGs, particularly hunger, poverty and energy access. Investment needs for such complementary policies are only a small fraction of the overall mitigation investments in 1.5°C pathways. (*high confidence*) {2.4.3, 5.4.2, Figure 5.5}

D.5 Limiting the risks from global warming of 1.5°C in the context of sustainable development and poverty eradication implies system transitions that can be enabled by an increase of adaptation and mitigation investments, policy instruments, the acceleration of technological innovation and behaviour changes (*high confidence*). {2.3, 2.4, 2.5, 3.2, 4.2, 4.4, 4.5, 5.2, 5.5, 5.6}

D.5.1 Directing finance towards investment in infrastructure for mitigation and adaptation could provide additional resources. This could involve the mobilization of private funds by institutional investors, asset managers and development or investment banks, as well as the provision of public funds. Government policies that lower the risk of low-emission and adaptation investments can facilitate the mobilization of private funds and enhance the effectiveness of other public policies. Studies indicate a number of challenges, including access to finance and mobilization of funds. (*high confidence*) {2.5.1, 2.5.2, 4.4.5}

D.5.2 Adaptation finance consistent with global warming of 1.5°C is difficult to quantify and compare with 2°C. Knowledge gaps include insufficient data to calculate specific climate resilience-enhancing investments from the provision of currently underinvested basic infrastructure. Estimates of the costs of adaptation might be lower at global warming of 1.5°C than for 2°C. Adaptation needs have typically been supported by public sector sources such as national and subnational government budgets, and in developing countries together with support from development assistance, multilateral development banks, and United Nations Framework Convention on Climate Change channels (*medium confidence*). More recently there is a

growing understanding of the scale and increase in non-governmental organizations and private funding in some regions (*medium confidence*). Barriers include the scale of adaptation financing, limited capacity and access to adaptation finance (*medium confidence*). {4.4.5, 4.6}

D.5.3 Global model pathways limiting global warming to 1.5°C are projected to involve the annual average investment needs in the energy system of around 2.4 trillion USD2010 between 2016 and 2035, representing about 2.5% of the world GDP (*medium confidence*). {4.4.5, Box 4.8}

D.5.4 Policy tools can help mobilize incremental resources, including through shifting global investments and savings and through market and non-market based instruments as well as accompanying measures to secure the equity of the transition, acknowledging the challenges related with implementation, including those of energy costs, depreciation of assets and impacts on international competition, and utilizing the opportunities to maximize co-benefits (*high confidence*). {1.3.3, 2.3.4, 2.3.5, 2.5.1, 2.5.2, Cross-Chapter Box 8 in Chapter 3, Cross-Chapter Box 11 in Chapter 4, 4.4.5, 5.5.2}

D.5.5 The systems transitions consistent with adapting to and limiting global warming to 1.5°C include the widespread adoption of new and possibly disruptive technologies and practices and enhanced climate-driven innovation. These imply enhanced technological innovation capabilities, including in industry and finance. Both national innovation policies and international cooperation can contribute to the development, commercialization and widespread adoption of mitigation and adaptation technologies. Innovation policies may be more effective when they combine public support for research and development with policy mixes that provide incentives for technology diffusion. (*high confidence*) {4.4.4, 4.4.5}.

D.5.6 Education, information, and community approaches, including those that are informed by indigenous knowledge and local knowledge, can accelerate the wide-scale behaviour changes consistent with adapting to and limiting global warming to 1.5°C. These approaches are more effective when combined with other policies and tailored to the motivations, capabilities and resources of specific actors and contexts (*high confidence*). Public acceptability can enable or inhibit the implementation of policies and measures to limit global warming to 1.5°C and to adapt to the consequences. Public acceptability depends on the individual's evaluation of expected policy consequences, the perceived fairness of the distribution of these consequences, and perceived fairness of decision procedures (*high confidence*). {1.1, 1.5, 4.3.5, 4.4.1, 4.4.3, Box 4.3, 5.5.3, 5.6.5}

D.6 Sustainable development supports, and often enables, the fundamental societal and systems transitions and transformations that help limit global warming to 1.5°C. Such changes facilitate the pursuit of climate-resilient development pathways that achieve ambitious mitigation and adaptation in conjunction with poverty eradication and efforts to reduce inequalities (*high confidence*). {Box 1.1, 1.4.3, Figure 5.1, 5.5.3, Box 5.3}

D.6.1 Social justice and equity are core aspects of climate-resilient development pathways that aim to limit global warming to 1.5°C as they address challenges and inevitable trade-offs, widen opportunities, and ensure that options, visions, and values are deliberated, between and within countries and communities, without making the poor and disadvantaged worse off (*high confidence*). {5.5.2, 5.5.3, Box 5.3, Figure 5.1, Figure 5.6, Cross-Chapter Boxes 12 and 13 in Chapter 5}

D.6.2 The potential for climate-resilient development pathways differs between and within regions and nations, due to different development contexts and systemic vulnerabilities (*very high confidence*). Efforts along such pathways to date have been limited (*medium confidence*) and enhanced efforts would involve strengthened and timely action from all countries and non-state actors (*high confidence*). {5.5.1, 5.5.3, Figure 5.1}

D.6.3 Pathways that are consistent with sustainable development show fewer mitigation and adaptation challenges and are associated with lower mitigation costs. The large majority of modelling studies could not construct pathways characterized by lack of international cooperation, inequality and poverty that were able to limit global warming to 1.5°C. (*high confidence*) {2.3.1, 2.5.1, 2.5.3, 5.5.2}

D.7 Strengthening the capacities for climate action of national and sub-national authorities, civil society, the private sector, indigenous peoples and local communities can support the implementation of ambitious actions implied by limiting global warming to 1.5°C (*high confidence*). International cooperation can provide an enabling environment for this to be achieved in all countries and for all people, in the context of sustainable development. International cooperation is a critical enabler for developing countries and vulnerable regions (*high confidence*). {1.4, 2.3, 2.5, 4.2, 4.4, 4.5, 5.3, 5.4, 5.5, 5.6, 5, Box 4.1, Box 4.2, Box 4.7, Box 5.3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 13 in Chapter 5}

D.7.1 Partnerships involving non-state public and private actors, institutional investors, the banking system, civil society and scientific institutions would facilitate actions and responses consistent with limiting global warming to 1.5°C (*very high confidence*). {1.4, 4.4.1, 4.2.2, 4.4.3, 4.4.5, 4.5.3, 5.4.1, 5.6.2, Box 5.3}.

D.7.2 Cooperation on strengthened accountable multilevel governance that includes non-state actors such as industry, civil society and scientific institutions, coordinated sectoral and cross-sectoral policies at various governance levels, gender-sensitive policies, finance including innovative financing, and cooperation on technology development and transfer can ensure participation, transparency, capacity building and learning among different players (*high confidence*). {2.5.1, 2.5.2, 4.2.2, 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.5, 4.5.3, Cross-Chapter Box 9 in Chapter 4, 5.3.1, 5.5.3, Cross-Chapter Box 13 in Chapter 5, 5.6.1, 5.6.3}

D.7.3 International cooperation is a critical enabler for developing countries and vulnerable regions to strengthen their action for the implementation of 1.5°C-consistent climate responses, including through enhancing access to finance and technology and enhancing domestic capacities, taking into account national and local circumstances and needs (*high confidence*). {2.3.1, 2.5.1, 4.4.1, 4.4.2, 4.4.4, 4.4.5, 5.4.1 5.5.3, 5.6.1, Box 4.1, Box 4.2, Box 4.7}.

D.7.4 Collective efforts at all levels, in ways that reflect different circumstances and capabilities, in the pursuit of limiting global warming to 1.5°C, taking into account equity as well as effectiveness, can facilitate strengthening the global response to climate change, achieving sustainable development and eradicating poverty (*high confidence*). {1.4.2, 2.3.1, 2.5.1, 2.5.2, 2.5.3, 4.2.2, 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.5, 4.5.3, 5.3.1, 5.4.1, 5.5.3, 5.6.1, 5.6.2, 5.6.3}

Box SPM.1: Core Concepts Central to this Special Report

Global mean surface temperature (GMST): Estimated global average of near-surface air temperatures over land and sea ice, and sea surface temperatures over ice-free ocean regions, with changes normally expressed as departures from a value over a specified reference period. When estimating changes in GMST, near-surface air temperature over both land and oceans are also used.[19] {1.2.1.1}

Pre-industrial: The multi-century period prior to the onset of large-scale industrial activity around 1750. The reference period 1850–1900 is used to approximate pre-industrial GMST. {1.2.1.2}

Global warming: The estimated increase in GMST averaged over a 30-year period, or the 30-year period centred on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multi-decadal warming trend is assumed to continue. {1.2.1}

Net zero CO_2 emissions: Net zero carbon dioxide (CO_2) emissions are achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period.

Carbon dioxide removal (CDR): Anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO_2 uptake not directly caused by human activities.

Total carbon budget: Estimated cumulative net global anthropogenic CO_2 emissions from the pre-industrial period to the time that anthropogenic CO_2 emissions reach net zero that would result, at some probability, in limiting global warming to a given level, accounting for the impact of other anthropogenic emissions. {2.2.2}

Remaining carbon budget: Estimated cumulative net global anthropogenic CO_2 emissions from a given start date to the time that anthropogenic CO_2 emissions reach net zero that would result, at some probability, in limiting global warming to a given level, accounting for the impact of other anthropogenic emissions. {2.2.2}

Temperature overshoot: The temporary exceedance of a specified level of global warming.

Emission pathways: In this Summary for Policymakers, the modelled trajectories of global anthropogenic emissions over the 21st century are termed emission pathways. Emission pathways are classified by their temperature trajectory over the 21st century: pathways giving at least 50% probability based on current knowledge of limiting global warming to below 1.5°C are classified as 'no overshoot'; those limiting warming to below 1.6°C and returning to 1.5°C by 2100 are classified as '1.5°C limited-overshoot'; while those exceeding 1.6°C but still returning to 1.5°C by 2100 are classified as 'higher-overshoot'.

Impacts: Effects of climate change on human and natural systems. Impacts can have beneficial or adverse outcomes for livelihoods, health and well-being, ecosystems and species, services, infrastructure, and economic, social and cultural assets.

Risk: The potential for adverse consequences from a climate-related hazard for human and natural systems, resulting from the interactions between the hazard and the vulnerability and exposure of the affected system. Risk integrates the likelihood of exposure to a hazard and the magnitude of its impact. Risk also can describe the potential for adverse consequences of adaptation or mitigation responses to climate change.

Climate-resilient development pathways (CRDPs): Trajectories that strengthen sustainable development at multiple scales and efforts to eradicate poverty through equitable societal and systems transitions and transformations while reducing the threat of climate change through ambitious mitigation, adaptation and climate resilience.

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19 Past IPCC reports, reflecting the literature, have used a variety of approximately equivalent metrics of GMST change.

Independent Statistics & Analysis
U.S. Energy Information Administration

Annual Energy Outlook 2021

with projections to 2050

Narrative

The *Annual Energy Outlook* explores long-term energy trends in the United States

- Projections in the *Annual Energy Outlook 2021* (AEO2021) are not predictions of what will happen, but rather, they are modeled projections of what may happen given certain assumptions and methodologies. By varying those assumptions and methodologies, AEO2021 can illustrate important factors in future energy production and use in the United States.

- Energy market projections are uncertain because many of the events that shape energy markets—as well as future developments in technologies, demographics, and resources—cannot be foreseen with certainty. To illustrate the importance of key assumptions, AEO2021 includes a Reference case and side cases that systematically vary important underlying assumptions.

- The U.S. Energy Information Administration (EIA) develops the AEO by using the National Energy Modeling System (NEMS), an integrated model that captures interactions of economic changes and energy supply, demand, and prices.

- The AEO is published to satisfy the Department of Energy Organization Act of 1977, which requires EIA's Administrator to prepare annual reports on trends and projections for energy use and supply.

What is the AEO2021 Reference case?

- The AEO2021 Reference case represents EIA's best assessment of how U.S. and world energy markets will operate through 2050, based on key assumptions intended to provide a baseline for exploring long-term trends.

- The Reference case serves as a reasonable baseline case that can be compared with the side cases that include alternative assumptions.

- EIA based the economic and demographic trends reflected in the Reference case on the current views of leading economic forecasters and demographers. For example, the Reference case projection assumes improvement in known energy production, delivery, and consumption technologies.

- The Reference case generally assumes that current laws and regulations that affect the energy sector, including laws that have end dates, remain unchanged throughout the projection period. This assumption enables EIA to use the Reference case as a benchmark to compare with alternative policy-based cases.

- The potential effects of proposed legislation, regulations, or standards are not included in the AEO2021 cases.

What are the side cases?

- Global market balances, primarily influenced by factors that are not modeled in NEMS, will drive future oil prices. In the AEO2021 High Oil Price case, the price of Brent crude oil, in 2020 dollars, reaches $173 per barrel (b) by 2050, compared with $95/b in the Reference case and $48/b in the Low Oil Price case.

- Compared with the Reference case, the High Oil and Gas Supply case reflects lower costs and greater resource availability for oil and natural gas in the United States, which allows for more production at lower prices. The Low Oil and Gas Supply case assumes fewer resources and higher costs.

- The High Economic Growth case and Low Economic Growth case address the effects of economic assumptions on the energy consumption modeled in the AEO2021. The two cases assume compound annual growth rates for U.S. gross domestic product of 2.6% and 1.6%, respectively, from 2020 to 2050, compared with 2.1% per year growth in the Reference case.

- The High Renewables Cost case and the Low Renewables Cost case examine the sensitivities surrounding capital costs for renewable electric power generating technologies. Capital cost reduction for an electric power generating technology is assumed to occur from learning by doing. The High Renewables Cost case assumes no cost reduction from learning for any renewable technologies. The Low Renewables Cost case assumes higher learning rates for renewable technologies through 2050, resulting in a cost reduction of about 40% from the Reference case by 2050.

Takeaways from the Reference and side cases

Returning to 2019 levels of US energy consumption takes years; energy related carbon dioxide emissions fall further before leveling off or rising

- Energy consumption fell faster than gross domestic product in 2020, and the pace at which both will return to 2019 levels remains uncertain.
- Petroleum remains the most-consumed fuel in the United States, as energy-related carbon dioxide emissions dip through 2035 before climbing in later years.
- The energy intensity of the U.S. economy continues to fall as end-use sector intensities decline at varying rates.

Renewable energy incentives and falling technology costs support robust competition with natural gas as coal and nuclear power decrease in the electricity mix

- Electricity demand grows at a modest rate throughout the projection period.
- As coal and nuclear generating capacity retires, new capacity additions come largely from natural gas and renewable technologies.
- Renewable electricity generation increases more rapidly than overall electricity demand through 2050.
- The cost-competiveness of solar photovoltaic and natural gas combined-cycle units leads to capacity additions.

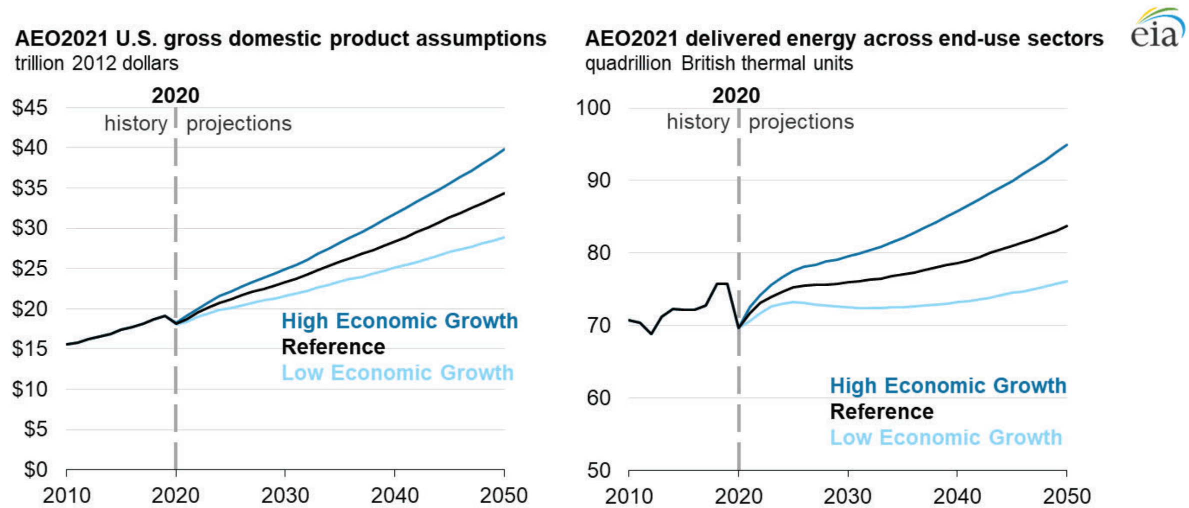
Continuing record-high domestic energy production supports natural gas exports but does not necessarily mean growth in the US trade balance in petroleum products

- Amid uncertainty, the United States continues to be an important global supplier of crude oil and natural gas.
- Motor gasoline remains predominant despite a growing mix of technologies in passenger vehicles.
- Natural gas consumption growth between 2020 and 2050 is concentrated in two areas: exports and industrial use.
- The amount of crude oil processed at U.S. refineries decreased in 2020 because of lower demand for transportation fuels, but it returns to 2019 levels by 2025.
- Consumption of biofuels as a share of the domestic fuel mix increases in AEO2021.

Energy consumption fell faster than gross domestic product in 2020, and the pace at which both will return to 2019 levels remains uncertain

Delivered energy consumption and gross domestic product decreased in 2020

Figure 1.

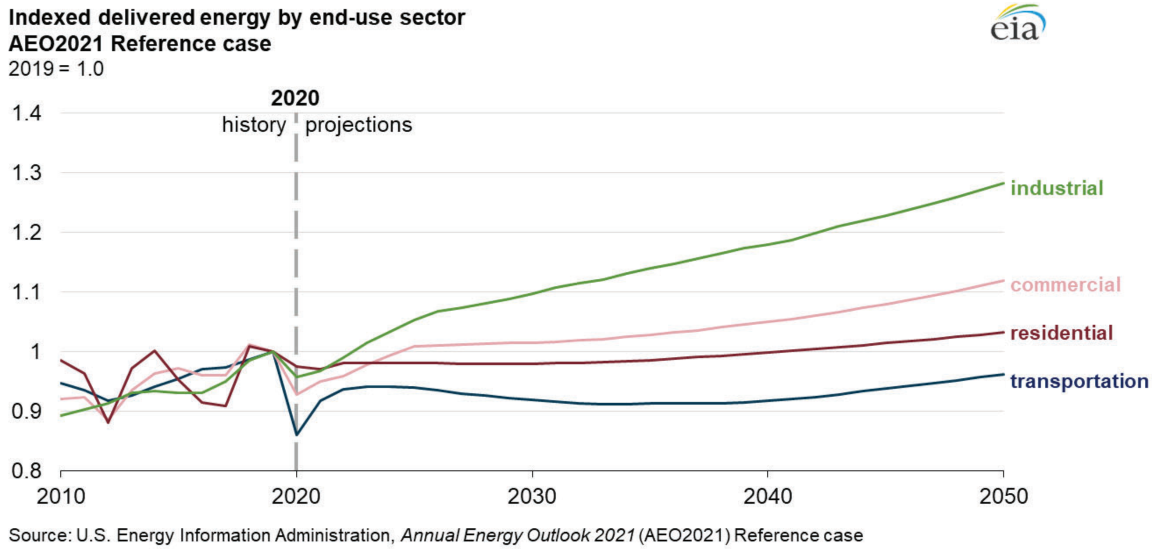


Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Economic Growth, and Low Economic Growth cases

The 2020 downturn in the U.S. economy stems from a series of demand shocks, both direct and indirect, that have resulted in large part from responses to the COVID-19 pandemic. Demand for energy delivered to the four U.S. end-use sectors (residential, commercial, transportation, and industrial) decreased to 90% of its 2019 level in 2020; a steeper decline than seen in real GDP. Compared with the financial crisis of 2008, the COVID-19-related decline in the total demand for delivered energy is about 70% larger. In the AEO2021 Reference case, EIA projects that U.S. energy demand takes until 2029 to return to 2019 levels.

Projections in AEO2021 focus on key factors driving longer-term demand for energy: growing economy and population; increasing use of renewables; increasing consumption of natural gas and electricity; and changing technology, behavior, and policy that affects energy efficiency in vehicles, end-use equipment, and lighting. These factors extend beyond the uncertainty resulting from the COVID-19 pandemic. The AEO2021 economic growth side cases provide alternative assumptions that reflect the uncertainties in the future growth of the U.S. economy. The economic growth cases also show the fastest and slowest rates of return to the 2019 level of total U.S. energy demand: in 2024 in the High Economic Growth case and in 2050 in the Low Economic Growth case, compared with 2029 in the Reference case.

Figure 2.



Responses to the pandemic decreased energy consumption in the transportation sector more than in the other end-use sectors

In the Reference case, energy consumption in the transportation sector remains lower than its 2019 level for the entire projection period because travel greatly decreased in 2020 as a result of lockdowns, and assumed improvements in fuel economy offset projected resumed travel growth. Responses to the COVID-19 pandemic including mobility restrictions, limitations on nonessential travel, and increased working from home greatly reduced long- and short-distance U.S. travel demands in 2020 compared with 2019. In the Reference case, U.S. passenger air travel demand decreases by nearly two-thirds in 2020 and returns in 2025 to 2019 levels; bus passenger travel demand decreases by nearly half in 2020 and returns in 2031 to 2019 levels; and light-duty vehicle (LDV) travel returns to 2019 levels by 2024.

As rising economic activity results in increased travel demands that surpass 2019 levels, energy consumption in aviation (excluding military use) to move passengers and goods across the world returns to its 2019 levels by 2030. However, energy consumption by light-duty and heavy-duty vehicles remains lower than 2019 levels for the entire projection period. Although travel demands increase for most modes, assumptions of increasing fuel efficiency slow growth in energy consumption. Energy consumption decreases in the Reference case because of the market-based adoption of energy efficiency technologies in new vehicles and the increasingly stringent federal fuel economy standards through for new light-duty vehicles (through 2026) and heavy-duty vehicles (through 2027). Efficiency improvements fully offset the consumption growth from LDV travel growth through 2043 and partially offset the consumption growth from heavy-duty vehicle travel growth through 2036. Continued growth of on-road travel increases energy use later in the projection period because the travel demand for both light- and heavy-duty vehicles outpaces fuel economy improvements.

Industrial energy consumption is projected to return to 2019 levels more rapidly than in other sectors

By 2025, industrial output in the United States returns to 2019 levels in the Reference case, although EIA projects that specific industries will return to 2019 levels at different rates. Industrial energy

consumption also declined in 2020, but EIA projects it to return to its 2019 levels by 2023, which is even faster than output growth and yields an increase in energy intensity in the near term. The U.S. industrial sector consumes more energy than any other end-use sector, and its energy use is projected to grow nearly twice as fast as any other end-use sector between 2020 and 2050. Metal-based durables, primary metals, and refining, all sensitive to net exports, contributed significantly to the 2020 decline in delivered energy consumption, while energy-intensive manufacturing and non-manufacturing industries drive the return to 2019 levels.

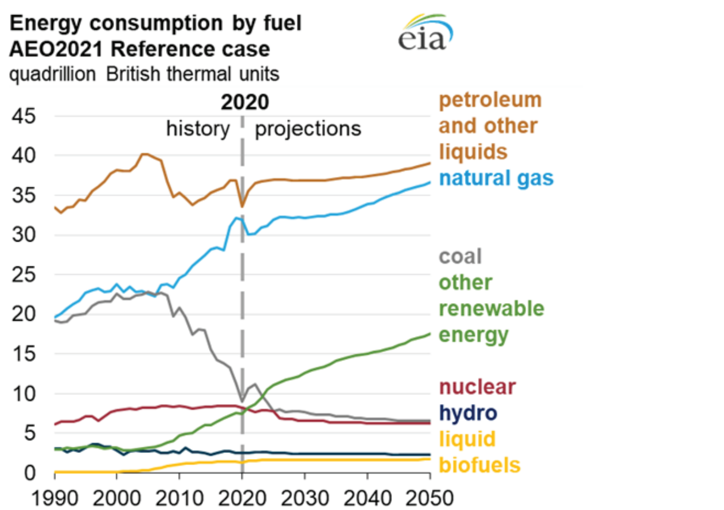
Energy consumption in buildings is least affected

Consumption of energy in commercial buildings declined in 2020, resulting in the largest single-year decline in buildings sector delivered energy consumption since 2012. However, in the Reference Case, energy consumption in commercial buildings returns to 2019 levels by 2025. Commercial and residential energy intensities—the ratio of delivered energy consumption to floorspace or building counts—suggest shifts in demand from increased working from home and videoconferencing in 2020 compared with 2019, although the increase in demand for energy by the residential sector is tempered by lower space heating needs resulting from a relatively warm 2019–2020 winter.

Consumption of energy in residential buildings remains stable through the short term because because working from home is moderating the effects of the economic downturn. Although Reference case energy consumption grows more slowly in residential buildings than in any other end-use sector between 2020 and 2050, increases in residential demand for cooling and electronic equipment offset efficiency improvements in many types of equipment, resulting in small increases in delivered energy consumption.

Petroleum remains the most-consumed fuel in the United States, as energy-related carbon dioxide emissions dip through 2035 before climbing in later years

Figure 3.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Vehicles and industrial processes are the main petroleum consumers in the Reference Case

Petroleum and other liquids remain the most-consumed fuel in the AEO2021 Reference case. The transportation sector is the largest consumer of petroleum and other liquids, particularly motor gasoline and distillate fuel oil. In the Reference Case, EIA assumes that current fuel economy standards stop requiring additional efficiency increases in 2026 for light-duty vehicles and in 2027 for heavy-duty vehicles. As travel continues to increase, consumption of petroleum and other liquids increases later in the projection period.

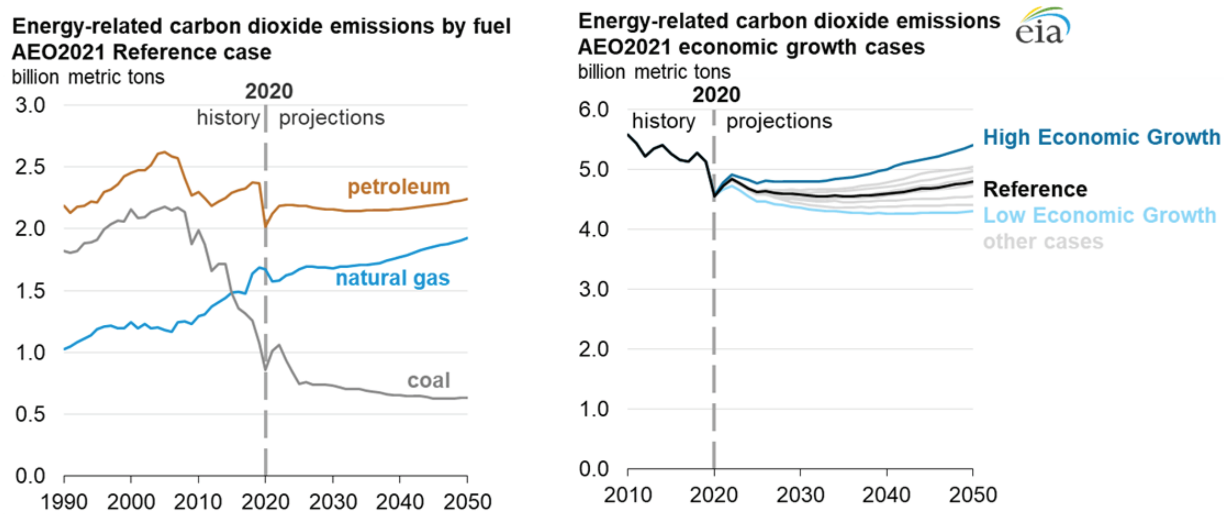
For industrial uses, petroleum remains the primary fuel for refining processes and for agriculture.

Coal continues a steady decline, as solar, wind, and natural gas use increases

In all cases, consumption of non-hydroelectric renewable energy is projected to be the fastest growing energy source. Policies at the state and federal level have encouraged significant investment in renewable resources for electricity generation and transportation fuels. New technologies have driven down the cost to install wind and solar generation, further increasing their competitiveness in the electricity market even as policy effects moderate over time. Federal regulation continues to encourage the use of biofuels, primarily ethanol, in the projection period. However, relatively modest increases in overall electricity and liquid fuel demand slow the projected growth of renewable energy in the Reference case.

EIA projects that consumption of natural gas will keep growing as well, driven by expectations that natural gas prices will remain low compared with historical levels. In the Reference case, the industrial sector becomes the largest consumer of natural gas starting in the early 2020s. This sector will expand the use of natural gas as a feedstock in the chemical industries, as well as for industrial heat and power.

Figure 4.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Economic Growth, and Low Economic Growth cases

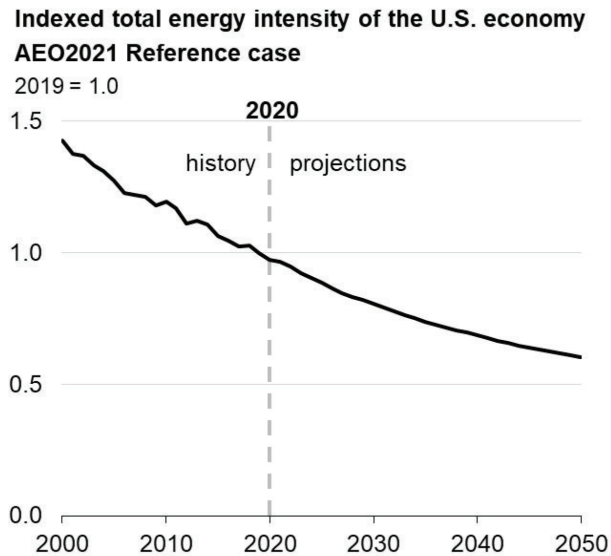
Coal use through 2050 generally declines with the retirement of coal-fired electricity generating units in the United States. In 2020, all power generation types, including coal, saw a decline in power demand because of COVID-19 response measures, but the decline in power demand affected coal to a greater extent because the annual average natural gas price fell to its lowest level in more than 20 years and as a result coal-fired generation was displaced by natural gas-fired generation.

Changes in fuel mix reduce Reference case emissions through 2035

Changes over time in carbon dioxide (CO2) emissions in the Reference case reflect the shift in fuel consumption: emissions decrease from 2023 to 2035 as a result of a transition away from more emission-intensive coal and a rise in the use of natural gas and renewable energy. After 2035, U.S. emissions begin to trend upward, reflecting the overall increase in the use of energy as a result of increasing population and economic growth. This trend holds true in all AEO2021 side cases. The High Economic Growth case has the largest increase in emissions, and the Low Economic Growth case has the lowest. Reductions in both energy intensity (energy consumption per gross domestic product) and carbon intensity (CO2 per energy consumption) both lessen the effects of economic growth. Even in the High Economic Growth case, energy-related CO2 emissions remain lower than the 2007 peak of 6 billion metric tons through 2050.

The energy intensity of the U.S. economy continues to fall as end-use sector intensities decline at varying rates

Figure 5.

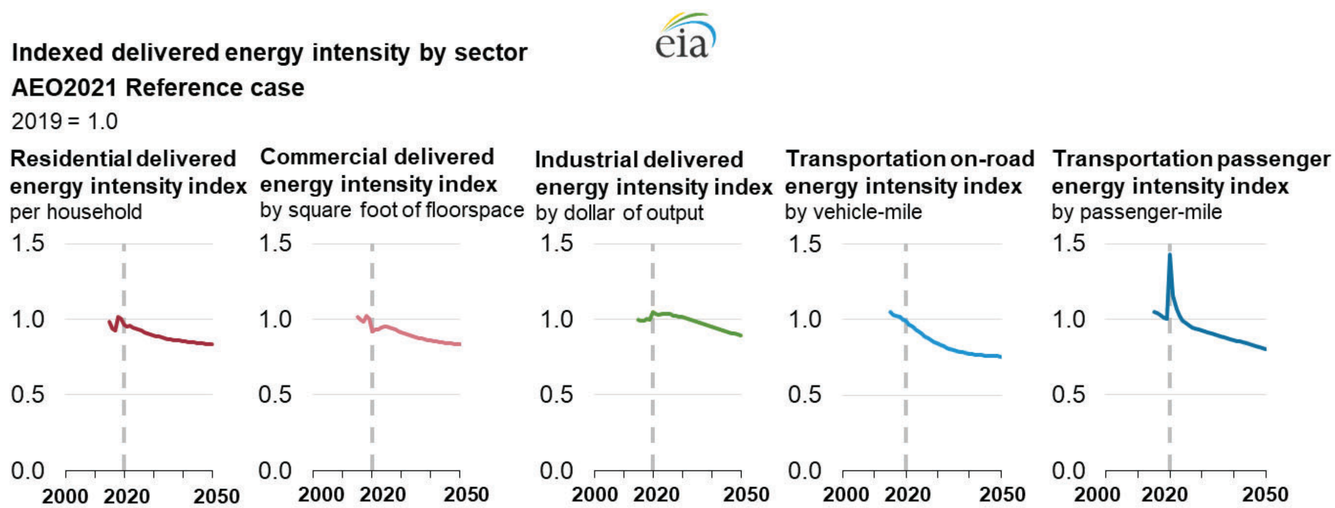


Note: Total energy intensity calculation reflects primary energy, which includes electricity losses.
Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Energy intensity declines across the entire economy

Total U.S. energy intensity—measured as the amount of primary energy consumed per dollar of GDP—continues to decrease slowly in the Reference case as real GDP increases faster than total energy consumption. In 2020, U.S. energy intensity is about half of what it was in 1990. In 2050, the ratio is about two-thirds of what it was in 2020. The U.S. economy becomes steadily less energy-intensive, although the rate of decrease is slower relative to recent history.

Figure 6.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Declines in energy intensity occur in each end-use sector

Energy is used in the economy to provide specific end-use services. Activities that consume energy provide indicators of efficiency (energy intensity) for each economic sector in the United States and vary in the Reference case projection as sectoral activity, technology choice, and utilization interact.

Industrial sector

Energy intensity in the U.S. industrial sector—measured as the amount of energy consumed by industry per dollar of industrial gross output—generally declines at nearly the same annual rate between 1990 and 2050 because of a continuing shift toward less energy-intensive manufacturing industries. Energy intensity increases in 2020 in response to lower utilization, but thereafter returns to a steady decline.

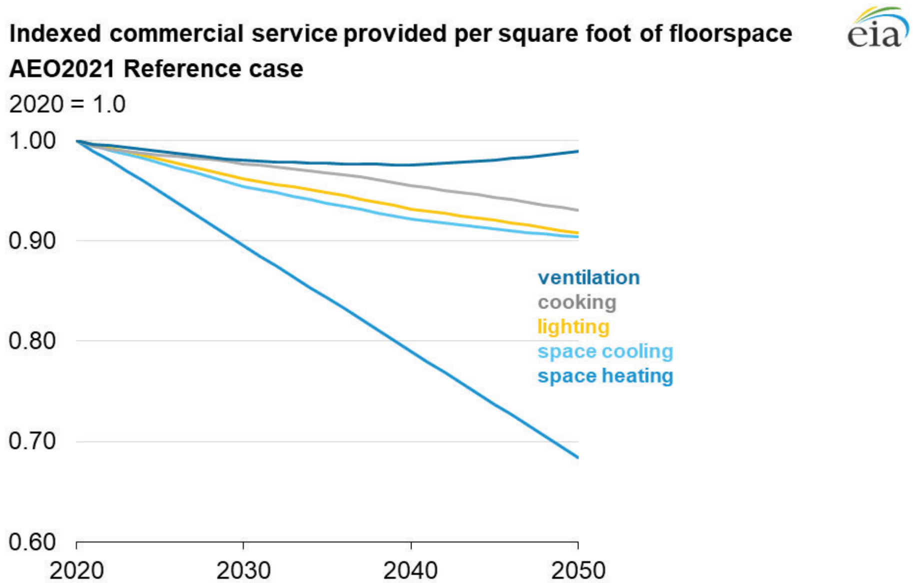
Transportation sector

Energy intensities in the U.S. transportation sector—measured as the amount of energy consumed in transportation per passenger-mile traveled for rail, air, and bus modes and per vehicle mile traveled for light-and heavy-duty vehicle modes—have different pathways in the short term. The collapse in passenger traffic arising from the pandemic, as measured by average load factors, results in an increasing amount of energy per passenger-mile: an energy intensity spike in the short term. After air load factors return to 2019 levels in 2024, the trend in energy intensity per passenger mile returns to a steady decline as rail, air, and bus modes adopt energy-efficient technologies and practices. After 2020, the combined energy intensity for light- and heavy-duty vehicles declines throughout the projection period because combined travel growth is fully offset by increases in fuel economy. The rate of decrease slows toward the end of the projection period because current fuel efficiency regulations require no additional increases in fuel economy for new light-duty vehicles after 2026 or for new heavy-duty vehicles after 2027.

Commercial and residential buildings sectors

EIA calculates energy intensity in the U.S. buildings sector as either the amount of energy consumed in buildings per square foot of commercial floorspace or the amount of energy consumed per residential household. Currently established increases in efficiency standards, building codes, and incentives lead to energy efficiency improvements, especially those attributed to energy management controls and sensors associated with space heating. These improvements, along with growth in distributed electricity generation including onsite solar—partially offset the effects of growth in the U.S. population, households, and commercial floorspace, which decreases energy intensity.

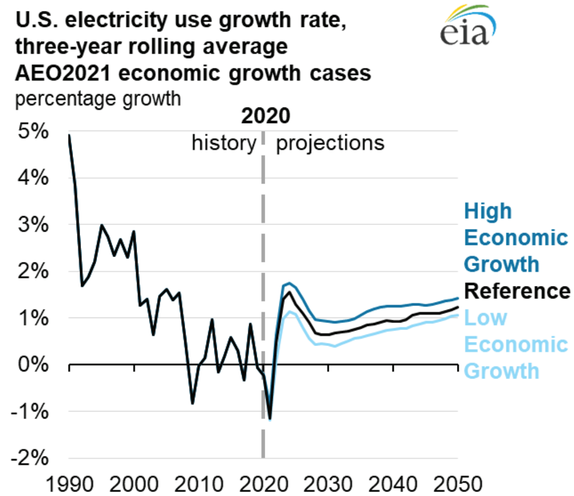
Figure 7.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Electricity demand grows at a modest rate throughout the projection period

Figure 8.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Economic Growth, and Low Economic Growth cases

Annual average electricity growth rate is less than 1% from 2020 to 2050 in the Reference case

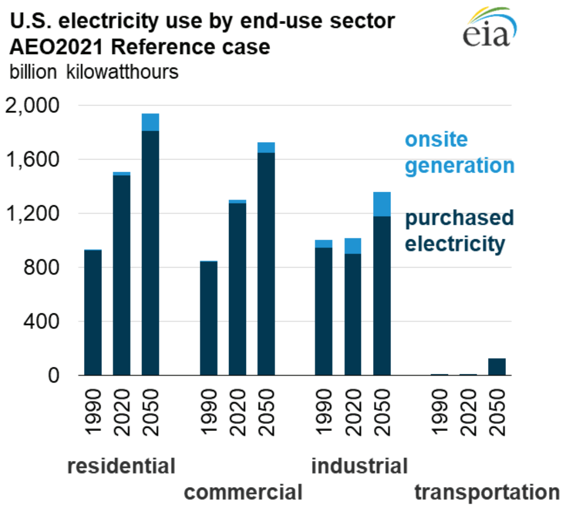
In the short term, demand for electricity may fluctuate as a result of year-to-year weather changes, but EIA projects that longer-term trends in electricity demand are driven by economic growth, and are somewhat offset by efficiency improvements. In the AEO2021 Reference case, after electricity demand returns to 2019 levels (following the impacts of COVID-19) in 2022, the average annual growth rate surpasses 1% only toward the end of the projection period. EIA projects electricity demand in the AEO2021 High Economic Growth case to grow at about one-quarter of a percentage point faster than in the Reference case, and it projects electricitiy demand in the Low Economic Growth case to grow at about one-quarter of a percentage point slower than in the Reference case.

COVID-19's projected impacts on electricity demand are short term in the Reference case

Although shifting weather patterns and efficiency improvements explain some of the near-term changes in electricity demand, the COVID-19 pandemic and associated economic downturn has a role as well, resulting in a near-term decline in electricity demand. EIA does not project long-term structural changes in electricity demand resulting from the pandemic, and the AEO2021 Reference case projects that demand largely returns to 2019 levels by 2025. Before 2025, higher residential sector demand partially offsets lower electricity demand from the commercial and industrial sectors.

The share of onsite electricity generation increases across non-transportation sectors

Figure 9.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

The growth in electricity sales from vendors is lessened by significant growth in onsite generation in the residential, commercial, and industrial sectors. Installation of rooftop photovoltaic (PV) systems, primarily on residential and commercial buildings, and combined-heat-and-power systems in industrial and some commercial applications, will account for more than 7% of total electricity generation by 2050, almost doubling the 2020 share of onsite power generators.

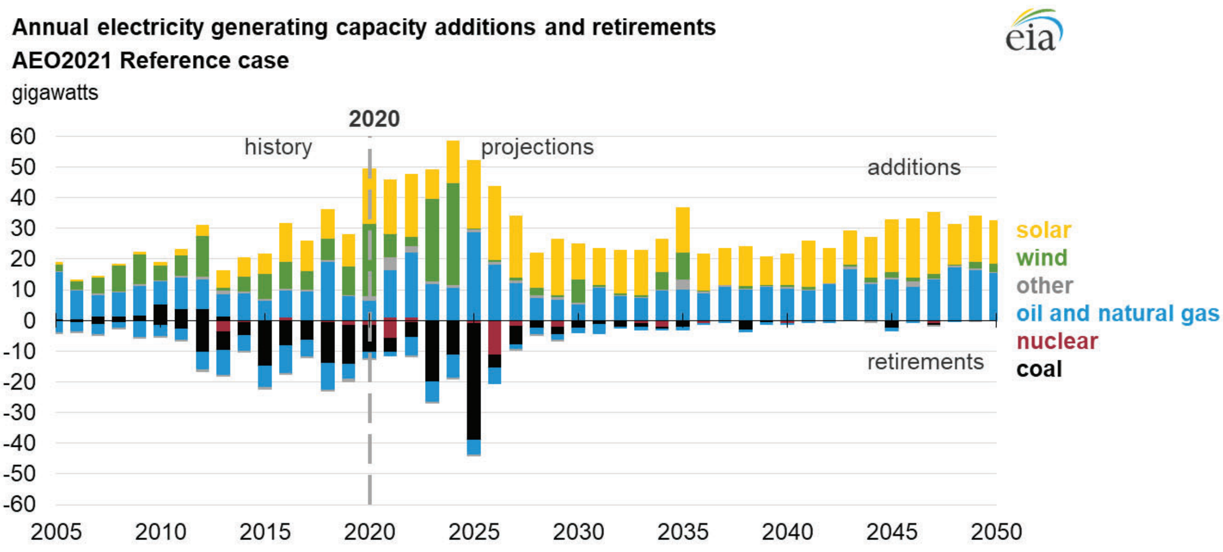
Electricity demand in transportation remains low

Although the greatest potential for increased electricity demand is within the transportation sector, electricity demand from this sector remains less than 3% of economy-wide electricity demand throughout the projection period. Current laws and regulations are not projected to induce much market growth, despite continuing improvements in electric vehicles (EVs) through evolutionary market developments. Both vehicle sales and utilization (miles driven) would need to increase substantially for EVs to raise electric power demand growth rates by more than a fraction of a percentage point per year.

As coal and nuclear generating capacity retires, new capacity additions come largely from natural gas and renewable technologies

Renewable technologies account for the majority of the projected capacity additions

Figure 10.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case and July 2020 Form EIA-860M

Renewable electric generating technologies account for almost 60% of the approximately 1,000 gigawatts of cumulative capacity additions projected in the AEO2021 Reference case from 2020 to 2050. The large share is a result of declining capital costs but is also a result of increasing renewable portfolio standard (RPS) targets and tax credits. Although wind contributes to renewable electric generating capacity additions, it is on a much smaller scale compared with solar capacity, which builds steadily throughout the projection period.

Wind additions are largely tied to policy

The projection now assumes the production tax credit (PTC) for wind runs for an extra year, or through 2024, following a one-year extension under the Taxpayer Certainty and Disaster Tax Relief Act of 2019, Division Q of the Further Consolidated Appropriations Act of 2020 passed in December 2019 and under the Internal Revenue Service's Notice 2020-41 issued in May 2020. Although capital costs for both wind and solar continue to decline throughout the projection period, without additional policy intervention, wind is not as cost-competitive as solar. More than two-thirds of cumulative wind capacity additions from 2020 to 2050 occur before the PTC expires at the end of 2024. The steadier pace of solar additions in part reflects the continued availability of a 10% investment tax credit (ITC), which continues in perpetuity after 2023 when the current 30% phases out.

Natural gas continues to be the fuel of choice for fossil-fuel capacity additions

Although renewable electric generating technologies account for about 60% of cumulative capacity additions throughout the projection period in the AEO2021 Reference case, natural gas-fired generators account for almost the entire remaining balance of additions—about 40% through 2050. These natural gas-fired generator additions are almost evenly split between combined-cycle technologies and

combustion turbines, which both provide energy and help balance the intermittent output from wind and solar generators.

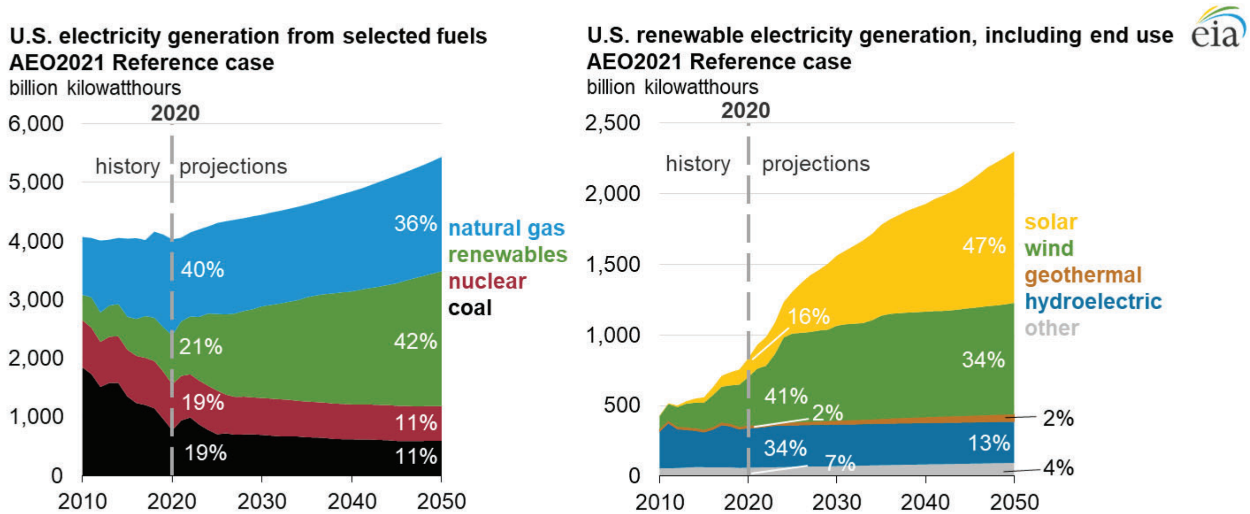
Coal-fired generating unit retirements largely take place by 2025

Most of the coal-fired generating capacity retirements assumed in the AEO2021 Reference case occur by 2025. The Reference case includes legislation and regulation as of September 2020, and so incorporated the EPA's Affordable Clean Energy (ACE) rule (84 FR 32520), which was vacated in the United States Court of Appeals for the District of Columbia Circuit on January 19, 2021. In AEO2021, the coal-fired plants remaining after ACE takes effect are more efficient and continue to operate throughout the projection period. Low natural gas prices in the early years of the projection period also contribute to the retirements of coal-fired and nuclear plants because both coal and nuclear generators are less profitable in these years, because natural gas generation generally sets power prices in wholesale electricity markets.

Renewable electricity generation increases more rapidly than overall electricity demand through 2050

Sustained low natural gas prices do not result in significant increases in the share of natural gas generation in the Reference case

Figure 11.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

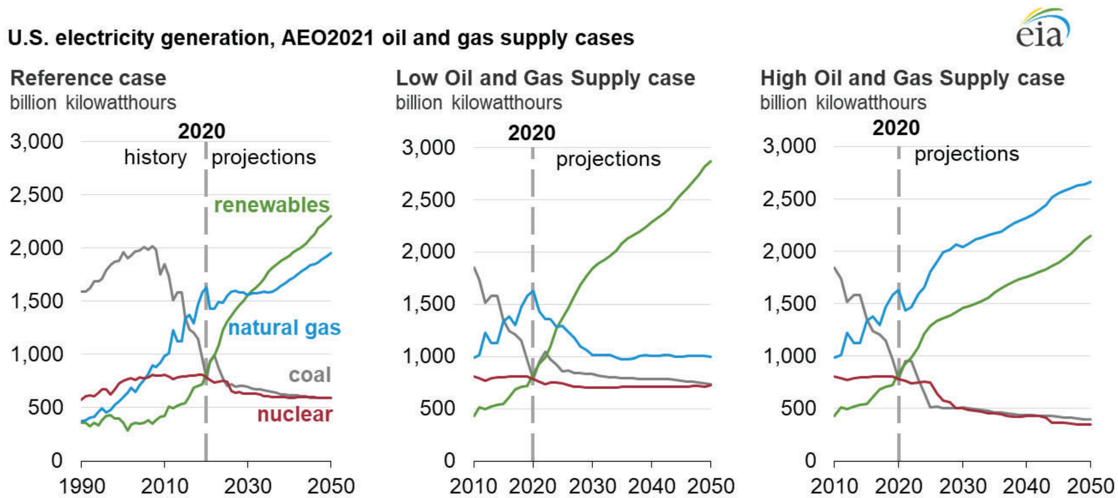
The share of natural gas in the generation mix remains flat, hovering at about one-third from 2020 to 2050. The share remains the same even though natural gas prices remain low (at or lower than $3.50 per million British thermal units) for most of the projection period, despite significant coal and nuclear generating unit retirements resulting from market competition, as regulatory and market factors induce more renewable electric generation.

Renewable electric generation is used to meet an increasing share of additional demand

As the share of natural gas-fired generation remains relatively flat, and as the contribution from the coal and nuclear fleets drops by half, the renewables' share of the electricity generation mix more than doubles from 2020 to 2050. Wind is responsible for most of the growth in renewables generation from 2020 through 2024, accounting for more than two-thirds of those increases in electricity generation during that period. After the production tax credit (PTC) for wind phases out at the end of 2024, solar generation is responsible for almost three-quarters of the increase in renewables generation. EIA assumes solar receives a 30% investment tax credit (ITC) through 2023, which is then reduced to a permanent value of 10% in 2024 and forward.

Impacts of COVID-19 on natural gas prices led to near-term trade-offs between coal and natural gas generation

Figure 12.

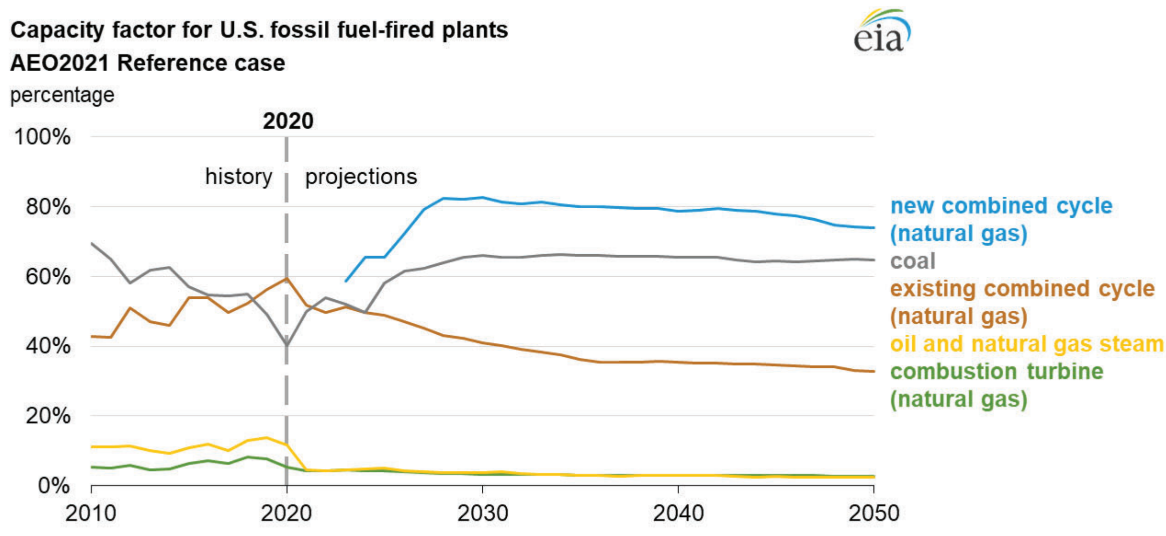


Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Oil and Gas Supply, and Low Oil and Gas Supply cases

In 2020, low heating demand early in the year because of warmer-than-normal weather, along with COVID 19-related demand reductions, led to natural gas production outpacing demand. The oversupply of natural gas led to the lowest natural gas prices since the 1990s. In addition, responses to the pandemic caused disruptions in the coal supply chain as mines temporarily closed to limit the spread of the virus. COVID 19-related impacts to the coal supply chain, as well as the lowest natural gas prices in a few decades, caused the projected share of coal-fired generation to decrease by over 4% in 2020 (from 23% in 2019 to 19% in 2020). At the same time, the share of natural gas-fired generation increased by about half that amount (from 38% in 2019 to 40% in 2020). EIA projects natural gas prices to increase by more than one-half in 2021 as the natural gas share of the generation mix returns to pre-COVID-19 levels and maintains that share through 2050. Similarly, coal generation in 2022 also increases with electricity demand and the rising natural gas prices before returning to its longer-term structural decline.

As more solar and wind energy is integrated into the electricity grid, natural gas-fired generating unit capacity factors steadily decrease

Figure 13.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

As a result of faster growing natural gas-fired generating capacity than natural gas-fired generation from 2020 to 2050, capacity factors for natural gas units decline steadily across all plant technology types. As more wind and solar capacity is added that displaces generation from both existing and new natural gas-fired generators, capacity factors for existing combined-cycle units will drop by nearly half from a peak of 60% in 2020. Natural gas accounts for over 40% of cumulative capacity additions from 2020 to 2050. About half of these additions are low-utilization combustion turbines, which are economically attractive when mostly used to provide infrequent peaking capacity. Energy storage systems, such as stand-alone batteries or solar/battery hybrid systems, are used as an arbitrage tool to move solar and other generation from periods of high supply and low demand to periods of low supply and high demand.

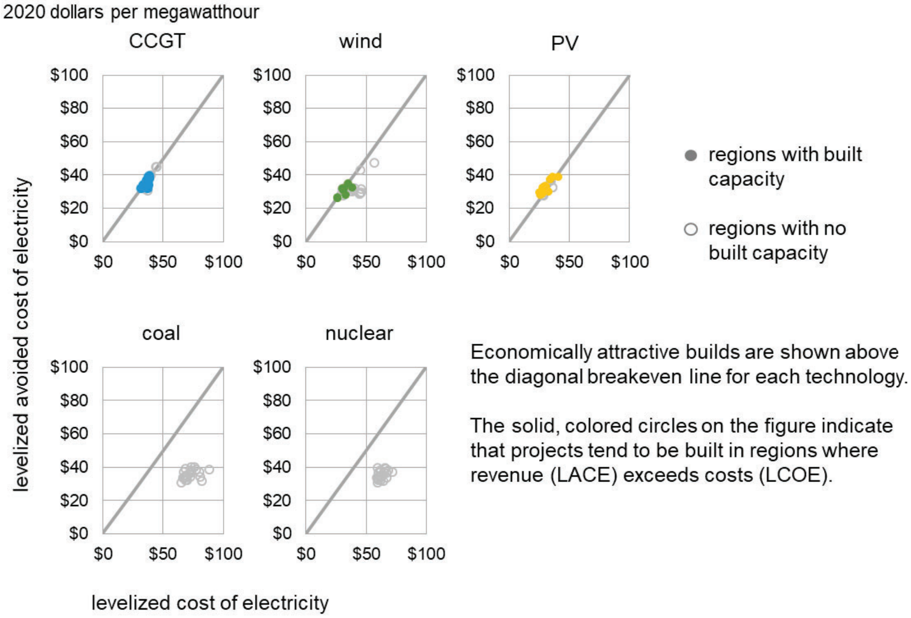
The cost-competitiveness of solar photovoltaic and natural gas combined-cycle units leads to capacity additions

Declining costs of intermittent renewable technologies, particularly solar photovoltaic, make solar cost-competitive with natural gas combined cycle

Figure 14.

Levelized avoided cost of electricity (LACE) and levelized cost of electricity (LCOE) by technology, 2026 online year, AEO2021 Reference case

2020 dollars per megawatthour



Note: CCGT = natural gas combined cycle, PV = solar photovoltaic
Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

In the AEO2021 Reference case, natural gas-fired combined-cycle and solar photovoltaic generators are the most economically attractive generating technologies when considering the overall cost to build and operate, as well as the value of the plant to the grid.

The levelized cost of electricity (LCOE) reflects the cost to build and operate a power plant per unit of generation, annualized over a cost-recovery period. The levelized avoided cost of electricity (LACE) represents a power plant's value to the grid, which is a proxy for a plant's potential revenues from the sales of electricity generated from displacing another marginal asset.

Both the levelized cost and levelized avoided cost of electricity, when used together, simplify the factors contributing to the capacity expansion decisions modeled. The value-cost-ratio (the ratio of LACE-to-LCOE) shows combined cycle and solar photovoltaic are the most economically competitive generating technologies.

In the AEO2021 Reference case, expected revenues from electricity generated from both natural gas-fired combined-cycle units and solar photovoltaic with single axis tracking units are generally greater than or equal to their respective projected costs across most of the electricity market regions in 2026.

Correspondingly, these two technologies show the greatest projected growth throughout the projection period. The value of wind approaches its cost in several regions. These regions see new wind capacity builds in the AEO2021 Reference case, primarily in advance of the phaseout of the production tax credit (PTC).

LACE accounts for both the variation in daily and seasonal electricity demand in the region where a new project is under consideration and the characteristics of the existing generation fleet where the new generating capacity will be added. The prospective new generation resource is compared with the mix of new and existing generation and capacity that it would displace. For example, a wind resource that would primarily displace existing natural gas-fired generation will usually have a different value than one that would displace existing coal-fired generation.

Amid uncertainty, the United States continues to be an important global supplier of crude oil and natural gas

Oil price is the primary driver of drilling and production

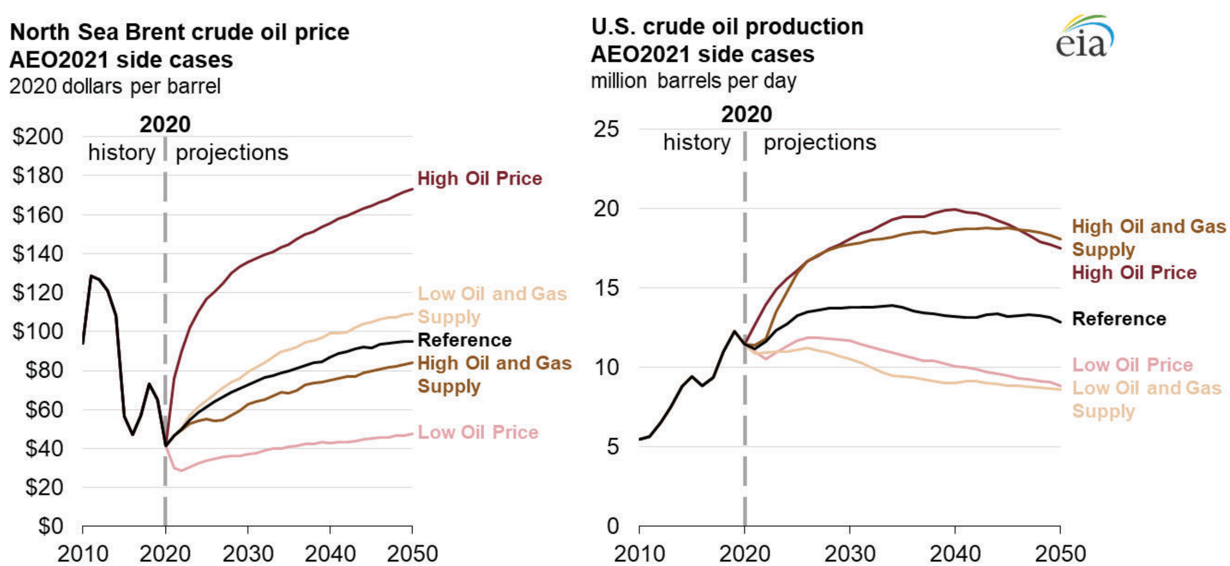
For both liquid fuels and natural gas, the effects of COVID-19 are primarily a short-term demand-side shock. Uncertainty surrounding post-pandemic expectations for oil and natural gas demand translates to uncertainties in supply through prices.

In AEO2021, the oil price is the primary driver of projected drilling activity and accompanying U.S. crude oil production rates. Thus, given the current economic downturn, EIA expects a lower price path in the short and medium term to decrease U.S. oil production rates compared with AEO2020.

Producers are more dependent on capital from cash flow

The oil and natural gas industry was already headed toward relying on capital from cash flow instead of debt and equity. COVID-19 has accelerated this trend, leaving producers more dependent on internal sources of cash flow because outside funding sources are less available or require higher rates of return. AEO2021 reflects these trends, with model changes including reducing drilling responsiveness to price increases in the short term and increasing the hurdle rate of return. Oil prices remain the most significant determining factor in oil production, and so if oil prices rapidly rise, as is seen in the High Oil Price case scenario, then production would follow suit.

Figure 15.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Oil and Gas Supply, Low Oil and Gas Supply, High Oil Price, and Low Oil Price cases

Reference case crude oil production remains at record-high levels for the next 30 years

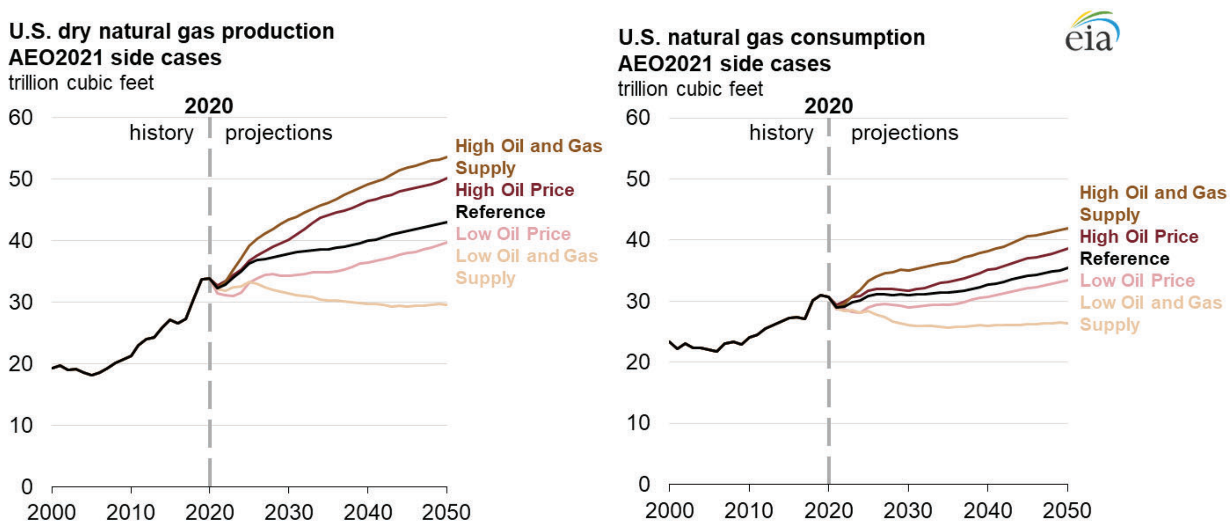
Starting in 2023, oil and natural gas production in the Reference case remains at historically high levels through 2050. The United States continues to be an integral part of global oil and natural gas markets and a significant source of global supply.

Domestic crude oil production in the Reference case returns to 2019 levels starting in 2023. In the long term, production continues to grow, generally plateauing in the later years of the projection period. The Brent crude oil price returns to 2019 levels after 2025 in the Reference case. Where the prices return quickly to pre-COVID-19 levels, as they do in the High Oil Price case, then crude oil production returns to 2019 levels more quickly. However, in the Low Oil Price case where oil prices are much lower than recent historical levels seen during the past 10 years, production never returns to pre-pandemic levels.

Tight oil is primarily driving the growth in the oil production outlook, followed by offshore resources. Tight oil production from the Wolfcamp play in the Permian Basin (Southwest region) and the Bakken play in the Williston Basin (Northern Great Plains region) leads the growth in U.S. tight oil production. However, estimates of technically recoverable tight or shale crude oil and natural gas resources are uncertain. The high and low oil and gas supply cases explore the impact of higher and lower resource supply levels on domestic production, including tight oil.

Natural gas production continues to grow, and end-use consumption and liquefied natural gas (LNG) trade remains uncertain

Figure 16.



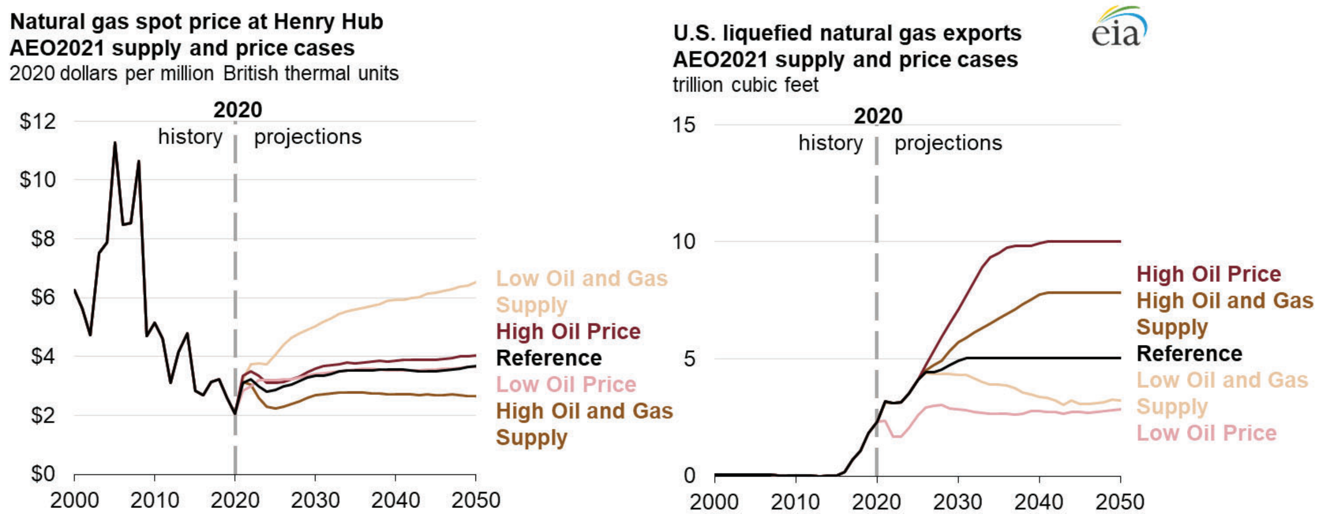
Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Domestic natural gas production in the Reference case also returns to pre-pandemic levels starting in 2023. In the long term, production continues to grow during the entire projection period, driven by end-use consumption and opportunities to sell natural gas internationally through LNG exports.

Shale gas and associated natural gas from oil plays are the primary contributors to this long-term growth. In the Reference case, more than half of the growth in shale gas production between 2020 and 2050 comes from shale gas plays in the Appalachian Basin in the East region, and most of the remaining growth comes from plays in the Gulf Coast and Southwest regions. Due to the drop in crude oil production, associated natural gas (natural gas produced in primarily oil formations) also decreased in 2020 because of the relatively low crude oil and natural gas prices. EIA projects associated natural gas

will return to 2019 levels in 2024 and then steadily increase at a modest rate through 2050, primarily driven by increased drilling in the Permian Basin.

Figure 17.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Oil and Gas Supply, Low Oil and Gas Supply, High Oil Price, and Low Oil Price cases

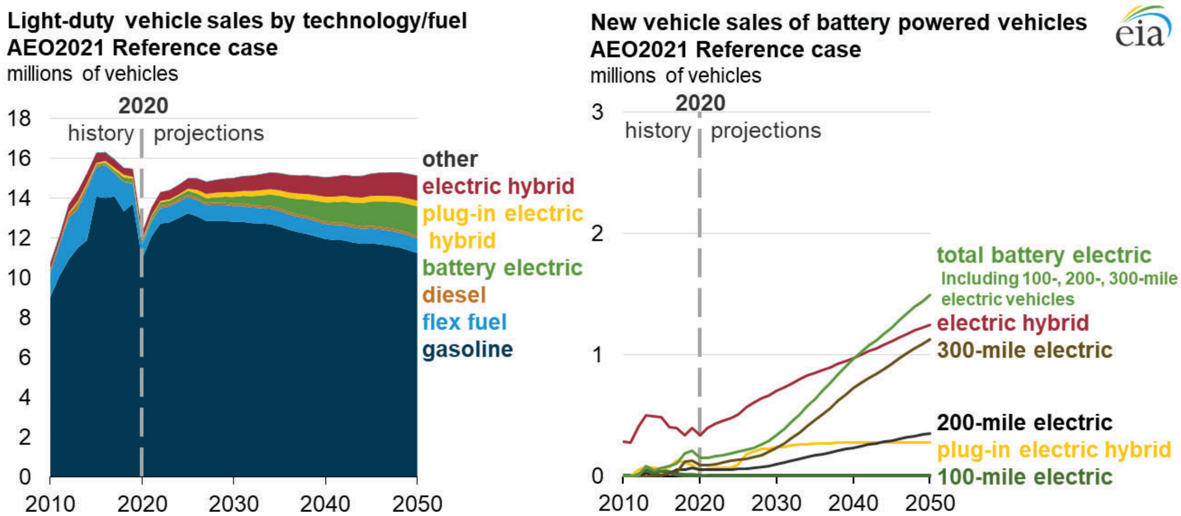
In the long term, because of expected increases in international demand for natural gas, EIA expects U.S. LNG exports to more than double between 2020 and 2029 in the Reference case.

The side cases display the uncertainty in international demand for and competitiveness of U.S. supply. Oil prices, which are traditionally used as a basis for global LNG price contracts, and U.S. natural gas prices both drive how competitive U.S. LNG exports are in global markets. The Oil and Gas Supply cases define the range of projected U.S. natural gas supply prices in the AEO 2021. Henry Hub natural gas spot prices remain below $3 per million British thermal units (MMBtu) in the High Oil and Gas Supply case and exceed $6/MMBtu by 2050 in the Low Oil and Gas Supply case.

With higher oil prices or lower U.S. natural gas domestic prices, LNG exports are much higher than in the Reference case, while the opposite occurs with lower oil prices or higher U.S. natural gas domestic prices.

Motor gasoline remains predominant despite a growing mix of technologies in passenger vehicles

Figure 18.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

The majority of new vehicles are powered by liquid fuels

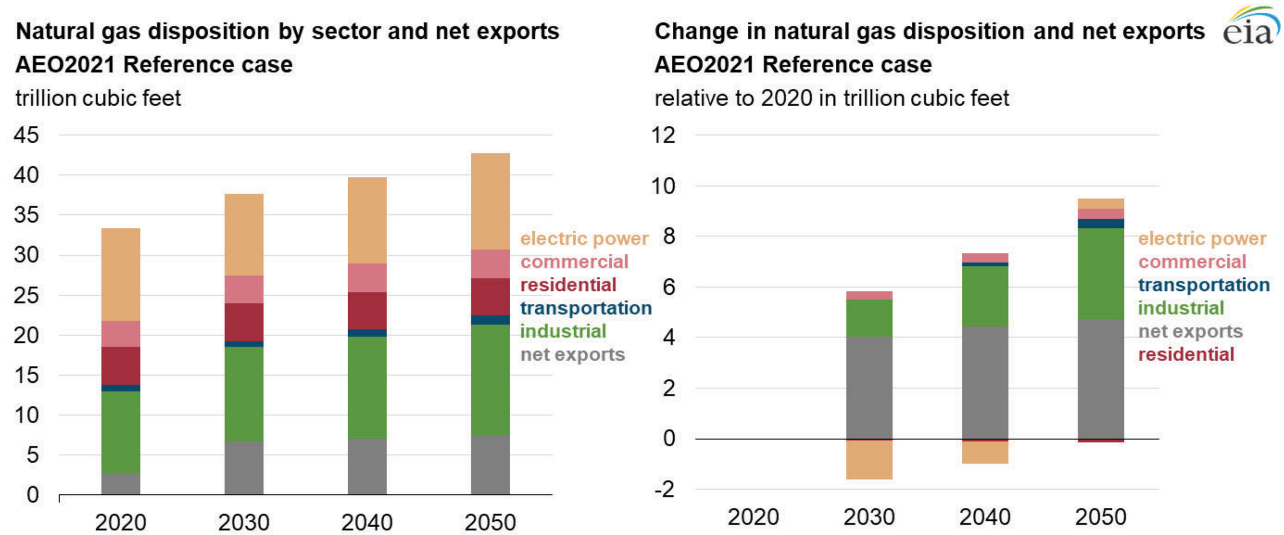
Spurred by rising incomes, increases in employment rates, and population growth, total annual sales of new light-duty vehicles (LDVs) in the United States in the Reference Case increase after the 2020 economic downturn before leveling off after 2025. EIA projects fewer sales of new LDVs in every year in the projection period than in 2019, although the market continues to grow for alternative technologies, particularly battery electric vehicles (BEVs). Gasoline and flex-fuel vehicles—which may use gasoline blended with up to 85% ethanol—accounted for 95% of the new LDV market in 2020, but their share of new-vehicle sales decreases to 79% in 2050. Both BEVs and electric hybrids increase their market shares of annual new LDV sales.

Motor gasoline consumption in U.S. transportation sector peaks in 2022

Because most light-duty vehicles have internal combustion engines, motor gasoline remains the major transportation fuel through 2050 as personal travel returns to pre-pandemic per-driver levels in the longer term. After pandemic response-related demand losses in 2020, consumption of motor gasoline in transportation peaks in about 2022 as fuel economy improvements partially offset travel growth. Motor gasoline use slowly trends lower thereafter as a result of further fuel economy improvements in new LDVs relative to travel growth, as well as increasing sales of energy-efficient alternative-fueled vehicles that further displace motor gasoline use.

Natural gas consumption growth between 2020 and 2050 is concentrated in two areas: exports and industrial use

Figure 19.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Natural gas production continues to grow during the entire projection period, driven by end-use consumption and opportunities to sell natural gas through LNG exports for international consumption. Large amounts of natural gas are consumed in the United States for various uses, for example space heating in buildings, thermal and feedstock requirements in industrial processes, and natural gas-fired electricity generation that is subsequently delivered as purchased electricity. Natural gas consumption growth between 2020 and 2050 is concentrated in two areas: exports and industrial use. All sectors in the United States are projected to increase natural gas consumption in 2050 relative to 2020 in the Reference case, except the residential sector.

The U.S. industrial sector leads future increases in domestic natural gas consumption

In the AEO2021 Reference case, the industrial sector is responsible for more of the growth in domestic natural gas consumption than any other U.S. sector because of the economic growth driving increased U.S. industrial output, coupled with a limited economic fuel-switching capability. Industrial firms are very price sensitive and tend to continue using natural gas as ample supply keeps industrial pricing attractive in the Reference case projection.

Although natural gas is consumed across the entire U.S. industrial sector, increased production of natural gas as well as low natural gas prices will especially benefit the chemical industry because of its requirements for raw material (feedstocks) and heat and power inputs. The bulk chemical industry, which includes production of organic chemicals (including petrochemicals), inorganic chemicals, resins, and agricultural chemicals, is responsible for almost half of the growth in industrial natural gas demand, including growth in both heat and power and feedstock used in producing methanol, nitrogenous fertilizers, and hydrogen. Most of this growth in liquid feedstock consumption is for hydrocarbon gas liquids (HGL), of which ethane and propane from the natural gas stream are the main components.

Natural gas-fired combined heat and power adds to industrial demand for natural gas

Taking advantage of combined-heat-and-power (CHP) technologies, the bulk chemical, refining, and paper industries use the most CHP in the United States because these large industries have high, well-defined heating needs, and therefore, process steam is readily available onsite to use for electricity generation. Low natural gas prices contribute to the increasing use of natural gas-fired CHP technology in the projections. Furthermore, paper and refining also use byproducts of their manufacturing processes as CHP fuel, so use of CHP in these industries tends to increase with output.

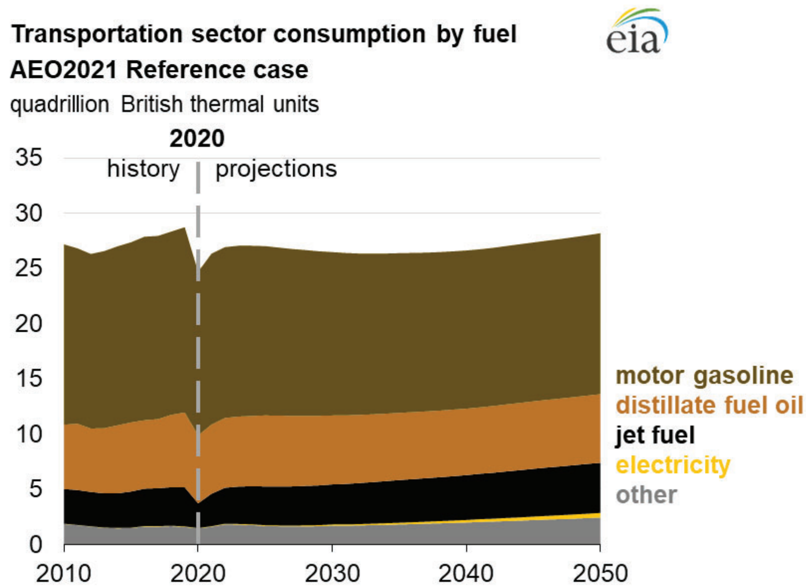
Consumption of natural gas in other sectors grows slowly

In the AEO2021 Reference case, power sector demand for natural gas-fired electricity generation increases at a much slower rate than either exports or industrial demand between 2020 and 2050. Even as natural gas-fired generation increases during the projection period, increased fleet efficiency from natural gas-fired generator additions of new combined-cycle electric generating technologies that operate at high usage levels—coupled with existing, less-efficient natural gas-fired technologies declining in use or retiring from the fleet—slow growth in natural gas consumption. Use of natural gas for transportation steadily increases through 2050 because of the improved economics of natural gas as a fuel for heavy-duty vehicles, but it remains at relatively low levels. The residential sector's consumption of natural gas is nearly flat, and commercial buildings show low-to-moderate growth, both as a result of final demand growth being tempered by energy efficiency improvements (particularly energy management controls and sensors) in space heating.

The amount of crude oil processed at U.S. refineries decreased in 2020 because of lower demand for transportation fuels, but it returns to 2019 levels by 2025

Lower refinery throughput in 2020

Figure 20.

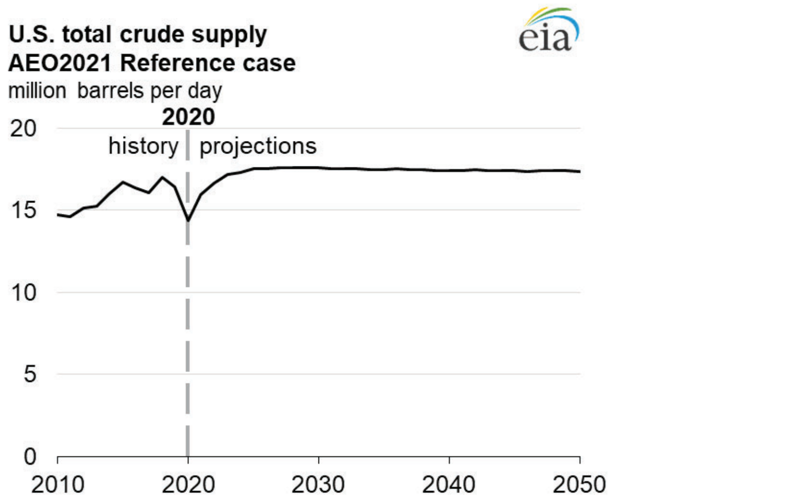


Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

As people stayed home and avoided nonessential travel during the pandemic, domestic (and global) demand for transportation fuels in 2020 decreased. Weekly U.S. consumption estimates for motor gasoline in particular recorded their lowest levels since January 1994. In response, U.S. refineries altered their operations to adjust to less end-use product demand, and total refinery throughput decreased in 2020.

Refineries can change their petroleum product output by changing how often and in what manner the downstream that processes the output from distillation units are run. Beginning in late March of 2020, because of responses aimed at slowing the spread of COVID-19, refinery yields for liquid fuels began to fall, as did refinery utilization. Crude oil throughput, or the amount of crude oil processed at refineries, decreased in 2020. In the Reference case, however, total refinery throughput returns to pre-COVID levels in about 2025, and utilization returns to pre-COVID levels sooner because of the permanent closures of some refining capacity.

Figure 21.

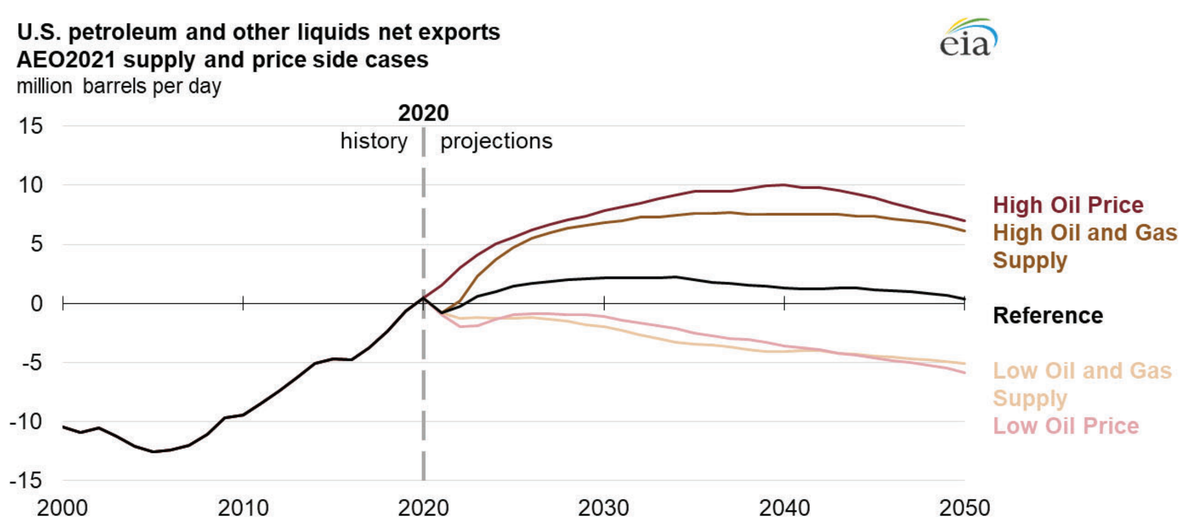


Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

Petroleum trade

In addition, refineries have lower capacity as a result of several closures and conversions of refineries in 2020. This factor puts further downward pressure on total crude processing, resulting in less petroleum product and more crude to be exported. The projected increase in domestic crude oil production, recovery in global liquid fuels demand, and increase in U.S. refinery inputs means the U.S. returns to net petroleum exporter status, on a volume basis, by 2024.

Figure 22.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference, High Oil and Gas Supply, Low Oil and Gas Supply, High Oil Price, and Low Oil Price cases

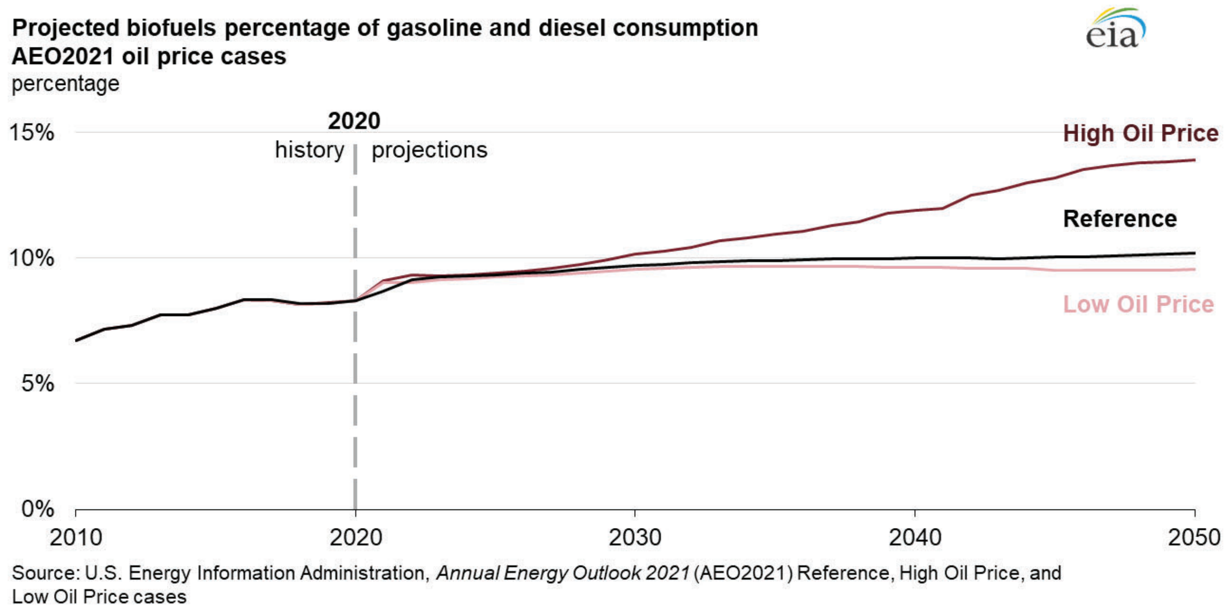
In the Reference case, the United States is both an importer and exporter of petroleum liquids, importing mostly heavy crude oil and exporting mostly petroleum products such as gasoline and diesel. Even though product exports in 2020 were lower than previous years, the AEO2021 Reference case projects relatively high levels of exports for petroleum and other liquids exports through 2050.

These high export levels are primarily a result of less consumption of liquid fuels in the United States and, to a lesser extent, a result because of domestic production of crude oil that cannot be processed economically domestically and is more valuable when exported. Net exports of petroleum and other liquids hold steady in the Reference case and stay in a similar range for the rest of the projection period.

The side cases illustrate the variable nature of U.S. petroleum trade. In the High Oil and Gas Supply side case, more resources and more availability result in increased domestic production and net exports. The High Oil Price case shows similar results: high production levels and accompanying exports. Whether it be higher supply or higher price, the effect is the same—the United States remains a net exporter during the entire projection period for those two cases. The opposite occurs in the Low Oil and Gas Supply case and Low Oil Price case. Generally, as a result of many possible oil price paths, production and throughput remain significantly uncertain.

Consumption of biofuels as a share of the domestic fuel mix increases in AEO2021

Figure 23.



Biofuels consumption decreases less than petroleum consumption

Although response to the COVID-19 pandemic affected demand for all liquid fuels in 2020, biofuel consumption has not decreased as much as petroleum-based fuels. AEO2021's Reference case shows biofuels production returning to 2019 levels in 2021, slightly faster than petroleum-based transportation fuels (motor gasoline and diesel), contributing to an increasing share of biofuels in the domestic fuel mix.

Biofuels consumption is supported by regulation

Biofuels consumption returns to 2019 levels faster than petroleum-based fuels mainly because of regulatory support, such as the federal Renewable Fuel Standard (RFS) program, which is administered by the U.S. Environmental Protection Agency (EPA) and is used to set annual U.S. renewable fuel volume targets. In the model, the RFS is a minimum level that must be met, so even when total transportation fuel demand drops, the RFS still requires a certain level of renewable fuel. State policy such as California's Low Carbon Fuel Standard (LCFS) is also designed to encourage domestic biofuels production.

Biofuels use increases as a share of the total in the Reference case

In this year's Reference case, EIA projects that the percentage of biofuels (including, ethanol, biodiesel, and other biomass) blended into the U.S. fuel pool (gasoline and diesel) will increase and slowly grow across the entire projection period. In the High Oil Price case, the share of biofuels consumed in the United States rises to a greater percentage as higher prices for gasoline and diesel make biofuels more competitive. The share of biofuels in the Low Oil Price case remains relatively unchanged when compared with the Reference case because of regulations like those previously mentioned. For example,

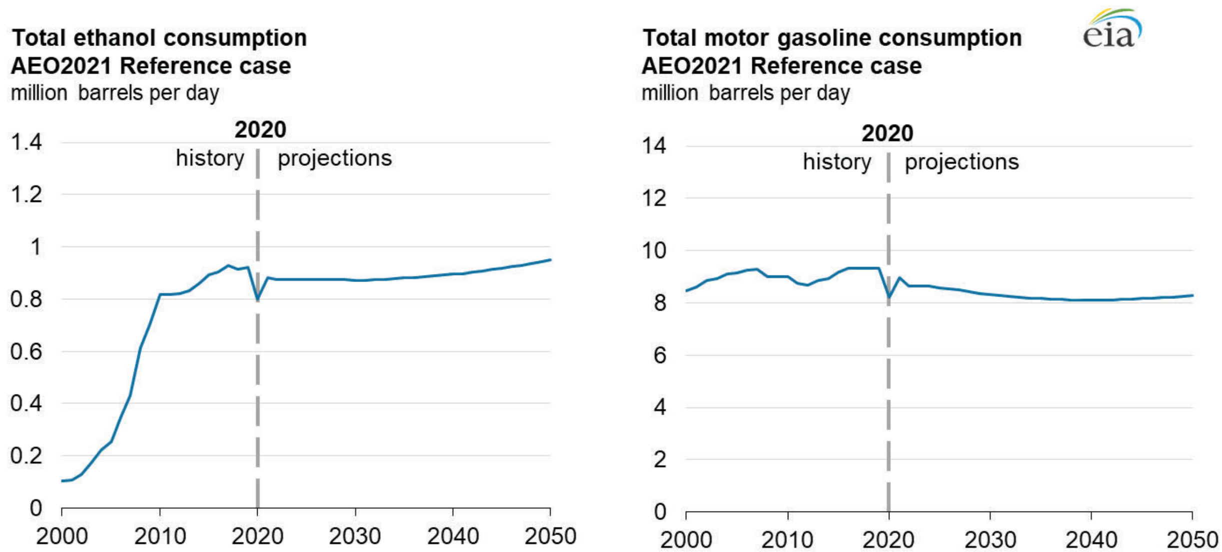
the LCFS encourages the use of biomass-based diesel because renewable diesel has one of the lowest carbon intensities of the approved pathways for LCFS compliance.

Individual biofuels supply

Biomass-based diesel, for the most part, tracks overall diesel demand. Biomass-based diesel is supported by policy including the renewed biodiesel mixture tax credit, and so it is likely to continue to gain market share through 2050. EIA projects diesel demand in the Reference case to almost return to pre-COVID levels in 2021, but never quite reach 2019's peak. EIA expects biodiesel to grow slightly, maintaining a steady level of production through 2050.

Several new renewable diesel plants have been announced this year, both domestically and overseas. A few domestic refineries have shuttered to convert to renewable diesel production, or they have made plans to do so in the near future, contributing to projected increases in renewable diesel supply.

Figure 24.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021* (AEO2021) Reference case

For ethanol, because almost all finished motor gasoline sold in the United States is blended with 10% ethanol (E10), reductions in gasoline demand have driven similar decreases in fuel ethanol demand, and, correspondingly, fuel ethanol production. Consumption of both ethanol and gasoline in 2020 have dropped by more than 10%, and both return in 2021 to almost reach 2019 levels at a similar pace. After this near-term return to 2019 levels, motor gasoline and diesel follow a pattern of general decrease, never fully returning to pre-COVID levels. On the other hand, ethanol does return to pre-COVID levels in the later years of the projection period, steadily growing through 2050 because of higher ethanol blends making their way into the on-road transportation pool.

12 Transportation

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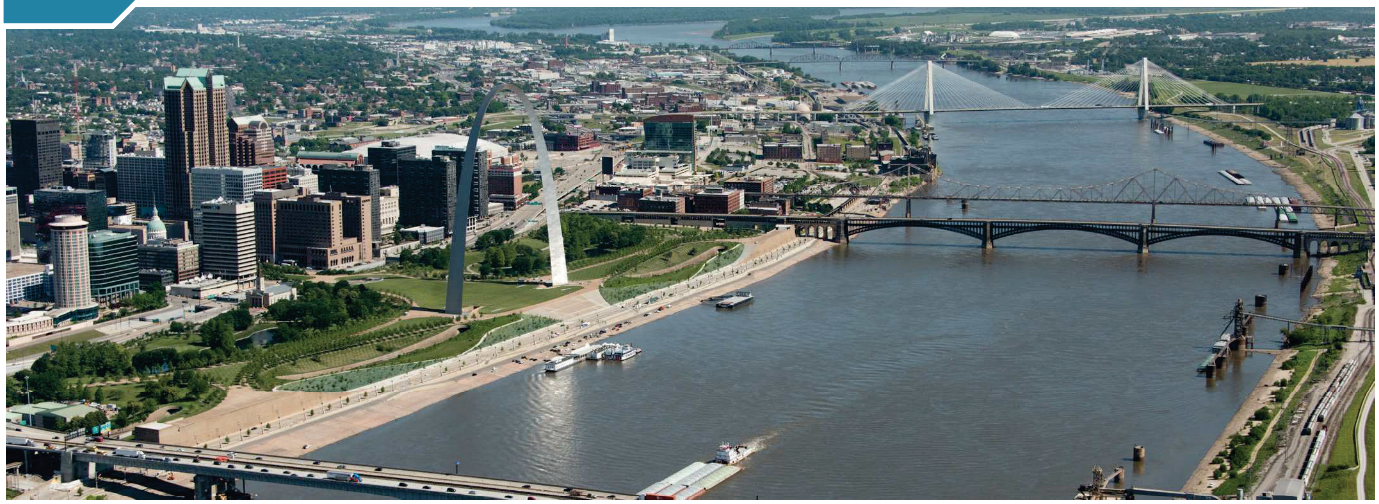
12 Transportation



St. Louis, Missouri

Key Message 1

Transportation at Risk

A reliable, safe, and efficient U.S. transportation system is at risk from increases in heavy precipitation, coastal flooding, heat, wildfires, and other extreme events, as well as changes to average temperature. Throughout this century, climate change will continue to pose a risk to U.S. transportation infrastructure, with regional differences.

Key Message 2

Impacts to Urban and Rural Transportation

Extreme events that increasingly impact the transportation network are inducing societal and economic consequences, some of which disproportionately affect vulnerable populations. In the absence of intervention, future changes in climate will lead to increasing transportation challenges, particularly because of system complexity, aging infrastructure, and dependency across sectors.

Key Message 3

Vulnerability Assessments

Engineers, planners, and researchers in the transportation field are showing increasing interest and sophistication in understanding the risks that climate hazards pose to transportation assets and services. Transportation practitioner efforts demonstrate the connection between advanced assessment and the implementation of adaptive measures, though many communities still face challenges and barriers to action.

Executive Summary

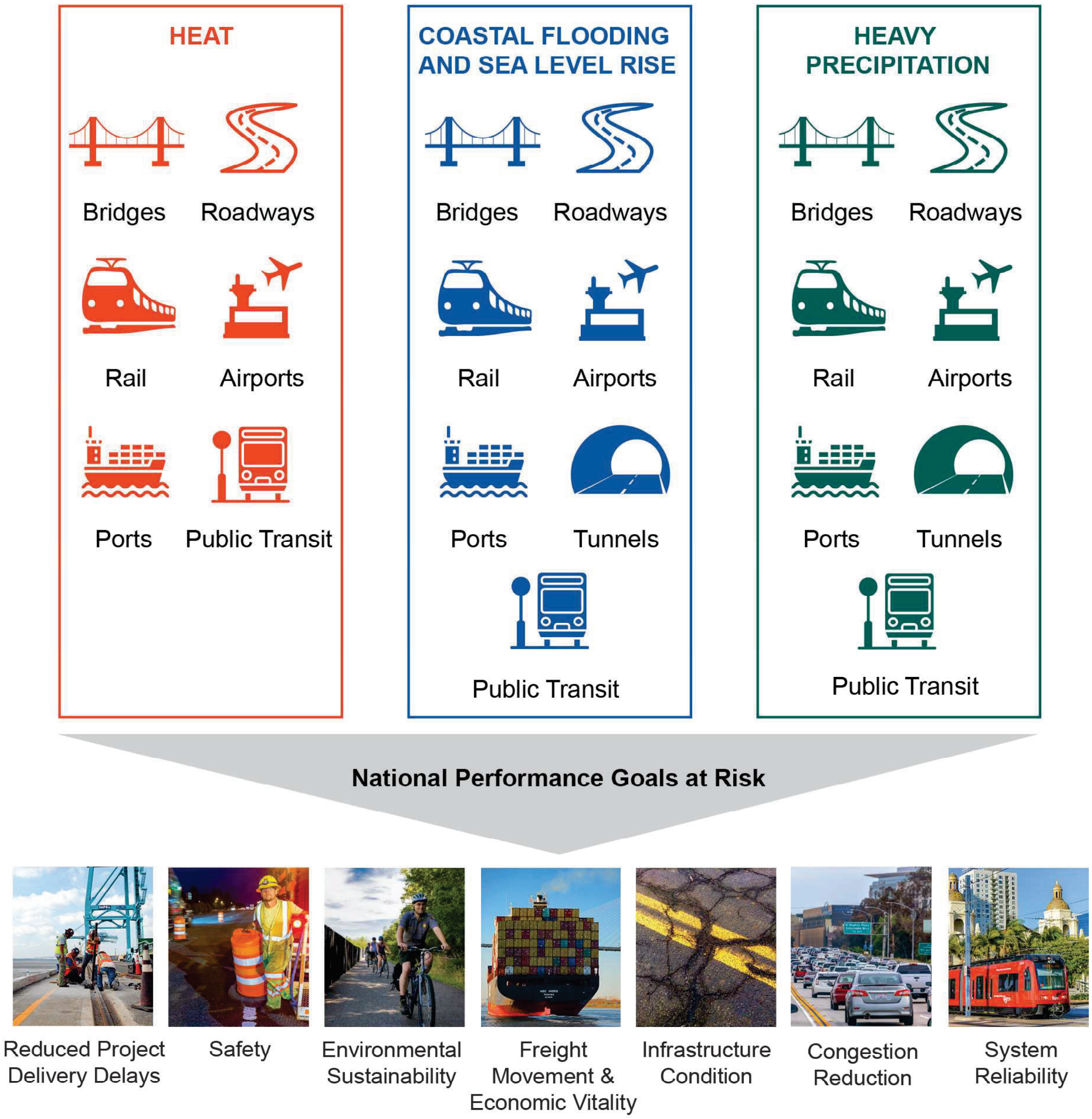
Transportation is the backbone of economic activity, connecting manufacturers with supply chains, consumers with products and tourism, and people with their workplaces, homes, and communities across both urban and rural landscapes. However, the ability of the transportation sector to perform reliably, safely, and efficiently is undermined by a changing climate. Heavy precipitation, coastal flooding, heat, wildfires, freeze–thaw cycles, and changes in average precipitation and temperature impact individual assets across all modes. These impacts threaten the performance of the entire network, with critical ramifications for economic vitality and mobility, particularly for vulnerable populations and urban infrastructure.

Sea level rise is progressively making coastal roads and bridges more vulnerable and less functional. Many coastal cities across the United States have already experienced an increase in high tide flooding that reduces the functionality of low-elevation roadways, rail, and bridges, often causing costly congestion and damage to infrastructure.[1,2] Inland transportation infrastructure is highly vulnerable to intense rainfall and flooding. In some regions, the increasing frequency and intensity of heavy precipitation events reduce transportation system efficiency[3] and increase accident risk. High temperatures can stress bridge integrity[4,5] and have caused more frequent and extended delays to passenger and freight rail systems and air traffic.[4,6]

Transportation is not only vulnerable to impacts of climate change but also contributes significantly to the causes of climate change. In 2016, the transportation sector became the top contributor to U.S. greenhouse gas emissions.[7] The transportation system is rapidly growing and evolving in response to market demand and innovation. This growth could make climate mitigation and adaptation progressively more challenging to implement and more important to achieve. However, transportation practitioners are increasingly invested in addressing climate risks, as evidenced in more numerous and diverse assessments of transportation sector vulnerabilities across the United States.

U.S. Transportation Assets and Goals at Risk

Climate Change and Notable Vulnerabilities of Transportation Assets



Heavy precipitation, coastal flooding, heat, and changes in average precipitation and temperature affect assets (such as roads and bridges) across all modes of transportation. The figure shows major climate-related hazards and the transportation assets impacted. Photos illustrate national performance goals (listed in 23 U.S.C. § 150) that are at risk due to climate-related hazards. *From Figure 12.1 (Source: USGCRP. Photo credits from left to right: JAXPORT, Meredith Fordham Hughes [CC BY-NC 2.0]; Oregon Department of Transportation [CC BY 2.0]; NPS–Mississippi National River and Recreation Area; Flickr user Tom Driggers [CC BY 2.0]; Flickr user Mike Mozart [CC BY 2.0]; Flickr user Jeff Turner [CC BY 2.0]; Flickr user William Garrett [CC BY 2.0] — see https://creativecommons.org/licenses/ for specific Creative Commons licenses).*

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State of the Sector

Transportation is the backbone of economic activity, connecting manufacturers with supply chains, consumers with products and tourism, and people with their workplaces, homes, and communities across both urban and rural landscapes. In 2017, the transportation sector added over $400 billion to the U.S. gross domestic product.[9] Transportation is also an important lifeline during emergencies, which may become increasingly common under climate change scenarios (see Kossin et al. 2017[10]). In the event of a disaster, roads, airports, and harbors may serve as key modes of evacuation and often become hubs for emergency personnel and relief supplies.

The transportation sector consists of a vast, interconnected system of assets and derived services, but a changing climate undermines the system's ability to perform reliably, safely, and efficiently (Figure 12.1). Heavy precipitation, coastal flooding, heat, and changes in average precipitation and temperature impact individual assets across all modes. These impacts threaten the performance (defined by national goals listed in 23 U.S.C. § 150[8]) of the entire network,[11] with critical ramifications for safety, environmental sustainability, economic vitality and mobility, congestion, and system reliability, particularly for vulnerable populations and urban infrastructure. Fortunately, transportation professionals have made progress understanding and managing risks, though barriers persist.

Particularly as impacts compound, climate change threatens to increase the cost of maintaining infrastructure[12] approaching or beyond its design life—infrastructure that is chronically underfunded.[13] Without considering climate impacts, the American Society of Civil Engineers[14] estimates that there is already a $1.2 trillion gap in transportation infrastructure needs. The transportation network is also interdependent on other sectors, such as energy and telecommunications, which have their own climate-related vulnerabilities and existing costs.

Transportation is vulnerable to the impacts of climate change, but it also contributes significantly to the causes of climate change. In 2016, the transportation sector became the top contributor to U.S. greenhouse gas emissions.[7] Low fuel prices, which lead to more driving, coupled with increasing volumes of freight trucking, containerized shipments, and air cargo, underlie the rise in transportation emissions.[15]

The transportation system is rapidly growing and evolving in response to market demand and innovation. Passenger miles traveled on highways and on commuter rail have increased approximately 250% and 175%, respectively, since 1960,[16] and similar trends are expected to continue.[15] Projected population growth of 30% to 50% by mid-century and significant expansion of existing urban centers and surrounding communities[17] will require the transportation system to grow and will place additional demands on the existing network. Long-haul freight is expected to increase 40% by 2040,[18] while air and marine transportation will continue to grow in tandem with economic growth and international trade. This population growth and land-use change can make climate mitigation, environmental sustainability, and adaptation progressively more challenging to implement and more important to achieve.

The shifting future of transportation presents new, pressing complexities and challenges. Transportation innovations such as shared mobility (for example, car sharing, carpooling, and ride-sourcing), transit-oriented development (TOD; that is, efforts to create compact, pedestrian-oriented, mixed-use communities centered around train systems), autonomous and electrified vehicles, Next Generation air transportation technologies, megaships, and hull-cleaning robots are

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emerging, but their impact on and vulnerability to climate change are still largely uncertain. For example, TOD, one of the older innovative transportation solutions, is very likely to reduce emissions and help build resilience.[19,20,21,22,23] Fuel consumption impacts of autonomous vehicles could vary greatly, depending on how they are deployed.[24] Similarly unclear is the impact that new transportation patterns, combined with deteriorating infrastructure, population growth, and land-use change, will have on the system's ability to adapt to climate change.

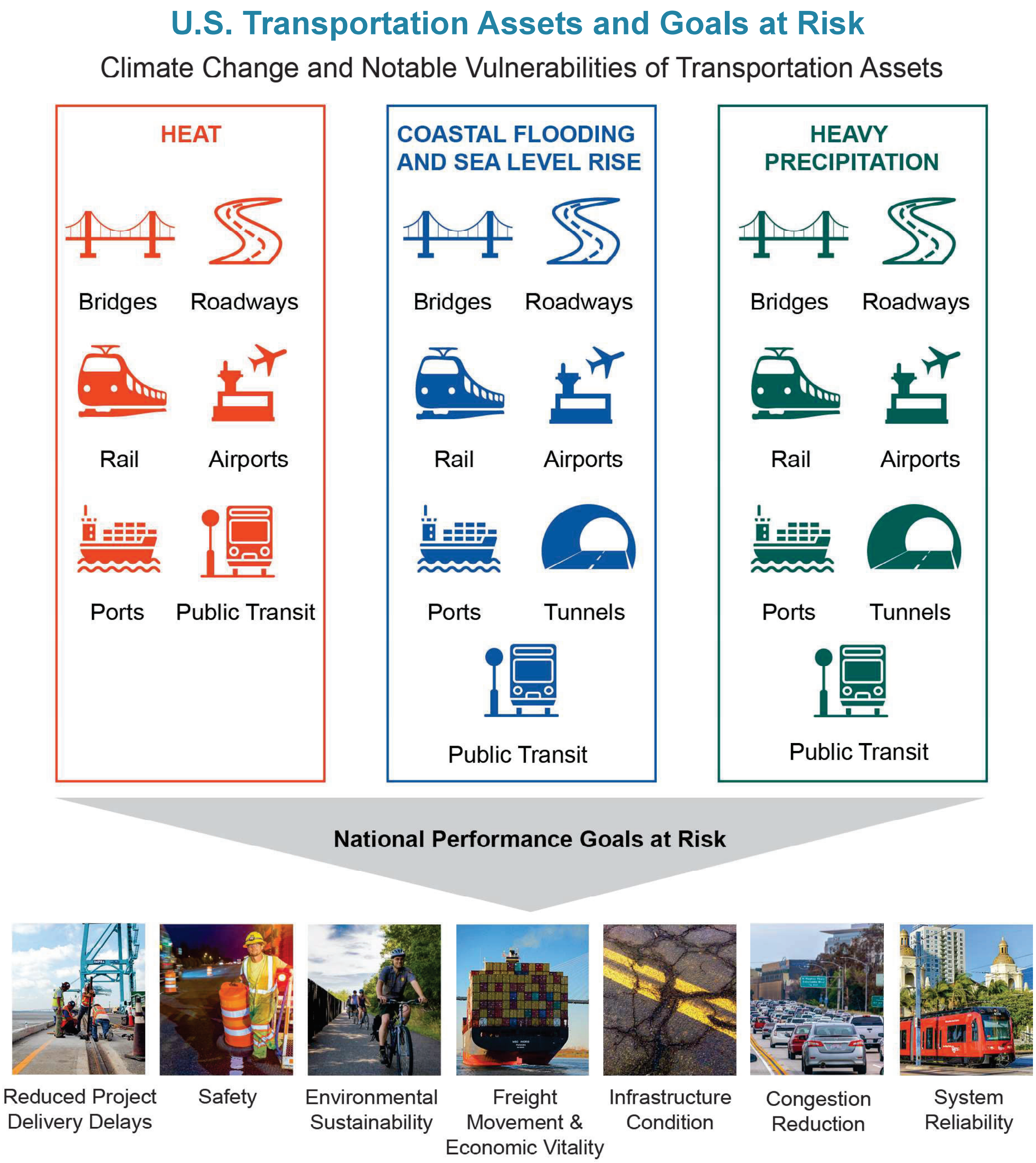

Figure 12.1: Heavy precipitation, coastal flooding, heat, and changes in average precipitation and temperature affect assets (such as roads and bridges) across all modes of transportation. The figure shows major climate-related hazards and the transportation assets impacted. Photos illustrate national performance goals (listed in 23 U.S.C. § 150[8]) that are at risk due to climate-related hazards. Source: USGCRP. Photo credits from left to right: JAXPORT, Meredith Fordham Hughes [CC BY-NC 2.0]; Oregon Department of Transportation [CC BY 2.0]; NPS–Mississippi National River and Recreation Area; Flickr user Tom Driggers [CC BY 2.0]; Flickr user Mike Mozart [CC BY 2.0]; Flickr user Jeff Turner [CC BY 2.0]; Flickr user William Garrett [CC BY 2.0].

Regional Summary

Precipitation changes are projected to vary across the country, with certainty about impacts much higher in some regions than others (Ch. 18: Northeast).[25] In the Northeast, rainfall volume and intensity have increased[25,26] and may impact transportation performance due to roadway washouts, bridge scour, and heaving or rutting due to freeze–thaw cycles, depending on site-specific conditions.[12,27,28,29] Intense precipitation at Northeast and mid-Atlantic airports has cascading effects on other airports and cargo movement networks, such as trucking and rail, due to delayed or canceled flights and stranded crews.[30,31,32] The projected increases in tropical cyclone wind speeds and rainfall intensity[33] by the end of the century indicate that shipments in Hawai‘i and the Pacific Islands may be interrupted more frequently and for longer periods.[34] Storms also cause erosion and dramatic changes to island coastlines, with associated damages to roadways, harbors, and airports (Ch. 27: Hawai‘i & Pacific Islands, KM 3).

In the Midwest, which has experienced an increase in riverine flooding resulting in long-term interstate freeway closures, future flooding is the main concern for transportation infrastructure (Ch. 21: Midwest, KM 5).[30] In Northeast urban regions, transportation network disruptions from high tide flooding are increasing and further stressing congested networks and storm water management systems (Ch. 18: Northeast, KM 3). Similarly, flooding in the Northwest has repeatedly blocked railways, flooded interstates, and halted freight movement, impacting access to critical services (Ch. 24: Northwest, KM 3 and 5). In the first three months of 2017, Spokane County, Washington, had already spent $2 million more than its yearly budget for road maintenance due to flooding from rapid snowmelt.[35] Flooding in the Pacific Northwest may also threaten access to recreation on federal lands, an economic driver for the region.[36]

Lack of precipitation is also a concern for the transportation network. In the past, high and low extremes in water levels in the Mississippi River and Great Lakes have limited boat traffic, affecting jobs and the ability of goods to get to domestic and international markets[37,38,39] and potentially increasing shipping costs in the future (Ch. 21: Midwest).[40]

In the Midwest, Northeast, Northern Great Plains, and Alaska, in particular, warming winters with fewer extremely cold days[41] and fewer snow and icing events[25] will likely extend the construction season, reduce winter road maintenance demand, and reduce vehicle accident risk.[42,43,44] However, when ice roads that run over a frozen water surface, such as a river or lake, start to thaw and allowable vehicle weight is therefore reduced, trucking and logging industries lose money due to limited access to road networks,[45] thus increasing transport costs (Ch. 26: Alaska, KM 5). Warming winters will also change the timing and location of freeze and thaw events, potentially increasing pavement cracking and pothole conditions in northern states.[12,45] In Alaska, near-surface permafrost thaw is responsible for severe damages to roads, airport runways, railroads, and pipelines (Ch. 26: Alaska).[46]

Climate change is projected to increase the costs of maintaining, repairing, and replacing infrastructure, with regional differences proportional to the magnitude and severity of impacts. Nationally, the total annual damages from temperature- and precipitation-related damages to paved roads are estimated at up to $20 billion under RCP8.5 in 2090 (in 2015 dollars, undiscounted, five-model average) (see the Scenario Products section of App. 3 for more on the RCPs). Inland flooding, projected to increase over the coming century, threatens approximately 2,500 to 4,600 bridges across the United States and is anticipated to result in average annual damages of $1.2 to $1.4 billion each year by 2050 (in 2015 dollars, undiscounted, five-model average).[47]

The transportation chapter of the Third National Climate Assessment highlighted Arctic warming, ports, weather-related disruptions, and adaptation strategies.[48] New research indicates that those findings are still valid concerns for the transportation sector. Some new research highlighted in this chapter includes 1) socioeconomic disparities in response to transportation vulnerabilities, 2) intermodal and cross-sector dependencies and strategies (moving toward a more holistic system as opposed to an asset-based analysis), and 3) communities' challenges, including rural communities, to identify and justify investment in transportation.

The three Key Messages discuss the physical impacts of specific climate hazards on the transportation system, economic implications of interrupted transportation, and the efforts transportation engineers, planners, and researchers are taking to understand and address current and future vulnerabilities.

Key Message 1

Transportation at Risk

A reliable, safe, and efficient U.S. transportation system is at risk from increases in heavy precipitation, coastal flooding, heat, wildfires, and other extreme events, as well as changes to average temperature. Throughout this century, climate change will continue to pose a risk to U.S. transportation infrastructure, with regional differences.

Coastal Risks

Sea level rise (SLR) is progressively making coastal roads and bridges more vulnerable and less reliable. The more than 60,000 miles of U.S. roads and bridges in coastal floodplains are clearly already vulnerable to extreme storms and hurricanes that cost billions in repairs.[49] Higher sea levels will cause more severe flooding and more damage during coastal storms and hurricanes.[50] Recent modeling shows how 1 foot of SLR combined with storm surge can result in more than 1 foot of increased storm surge.[51,52] Low-clearance bridges are particularly vulnerable to increased wave loads from storm surges that can dislodge a bridge deck.[53,54] Since the Third National Climate Assessment, new work has found that SLR has already contributed to damage of one major U.S. bridge during a hurricane: the 3-mile-long bridge carrying I-10 over Escambia Bay, in Pensacola, Florida, was severely damaged during Hurricane Ivan in 2004 (the same mechanism was observed in 2005 after Hurricane Katrina) by wave-induced loads due to a historically high storm surge.[53,55] Ports, which serve as a gateway for 99% of U.S. overseas trade,[56] are particularly vulnerable to climate impacts from extreme weather events associated with rising sea levels and tropical storm activity.[57] SLR and storm surge also threaten coastal airports.[58]

Global average sea levels are expected to continue to rise by at least several inches over the next 15 years and by 1–4 feet by 2100. This 1-to-4-foot range includes the likely projected ranges under all the RCP scenarios.[2] However, a rise of as much as 8 feet by 2100 is scientifically plausible due to possible Antarctic ice sheet instabilities.[2] Coastal infrastructure will be exposed to the effects of relative SLR, which includes vertical land motion in addition to regional variations in the distribution of the global SLR. For example, relative SLR will be higher than the global average on the East and Gulf Coasts of the United States because of the sum of these effects.[2] It is common practice for assessment and planning purposes to develop a range of scenarios of future sea levels that are consistent with these scientific estimates but not specifically based on any one. Scenarios developed by the Federal Interagency Sea Level Rise and Coastal Flood Hazard Scenarios and

Tools Task Force span the scientifically plausible range and include an Intermediate-Low scenario of 1.6 feet of global average sea level rise by 2100, an Intermediate scenario of 3.3 feet, and an Extreme scenario of 8.2 feet.[59] The relative SLR corresponding to some of these scenarios is used below to estimate increased coastal flooding delays.

Many coastal cities across the United States have experienced an increase in high tide flooding (Ch. 27: Hawai'i & Pacific Islands),[2] causing areas of permanent inundation and increased local flooding that reduce the functional performance for low-elevation roadways, rail, and bridges and often causing costly congestion and damage to infrastructure.[1,2] In Portsmouth, Virginia, one-third of residents report flooding in their neighborhoods at least a couple of times a year, and nearly half of residents were not able to get in or out of their neighborhoods at least once within the past year due to high tide flooding.[60] On the U.S. East Coast alone, more than 7,500 miles of roadway are located in high tide flooding zones. Unmitigated, this flooding has the potential to nearly double the current 100 million vehicle-hours of delay likely by 2020 (representing an 85% increase from 2010), with a 10-fold increase by 2060 even under the Intermediate-Low SLR scenario (Figure 12.2).[61] US Route 17 in Charleston, South Carolina, currently floods more than 10 times per year and is expected to experience up to 180 floods annually by 2045, with each flood costing the city $12.5 million (in 2009 dollars, undiscounted; $13.75 million in 2015 dollars) (Ch. 19: Southeast).[2] Even if a roadway is not inundated, higher groundwater tables from SLR can impact tunnels and utility corridors and weaken roadway base materials in low-lying coastal regions.[62,63,64,65]

Precipitation and Flooding Risks

In most parts of the United States, heavy precipitation is increasing in frequency and intensity, and more severe precipitation events are anticipated in the future.[25] Inland transportation infrastructure is highly vulnerable to intense rainfall and flooding, with impacts including less reliable transportation systems[3] and increased accident risk.[66,67] Extreme precipitation events annually shut down parts of the Interstate Highway System for days or weeks due to flooding and mudslides, as happened in the first five months of 2017 in, for example, northern California (I-80) and southern California (I-880) in January, north central California (I-5) in February, Idaho (I-86) in March, and the central United States including Missouri (I-44 and I-55) in May.

Nationally, projected future increases in inland precipitation over this century will threaten approximately 2,500 to 4,600 bridges by 2050, and 5,000 to 6,000 bridges by 2090, respectively, for the lower and higher scenarios (RCP4.5 and RCP8.5).[47] Bridge failure is most common during unprecedented floods.[68] Damage due to bridge scour can result during less extreme events. This occurs when sediment around piers and abutments is washed away, compromising bridges' structural integrity.[68] Increases in rainfall intensity can accelerate bridge foundation erosion and compromise the integrity and stability of scour-critical bridges.[69]

Freight movement at major international ports can be delayed under extreme weather events that include heavy rains and/or high winds affecting crane operations and truck service.[57] Even without such disruptions, major international trade gateways, hubs, and distribution centers already experience some of the worst congestion in the country.[15]

Transportation systems that are most vulnerable to the recent observed and projected increases in precipitation intensity[25] are those where drainage is already at capacity, where projected heavy rainfall events will occur over prolonged periods, and where changing winter

Annual Vehicle-Hours of Delay Due to High Tide Flooding

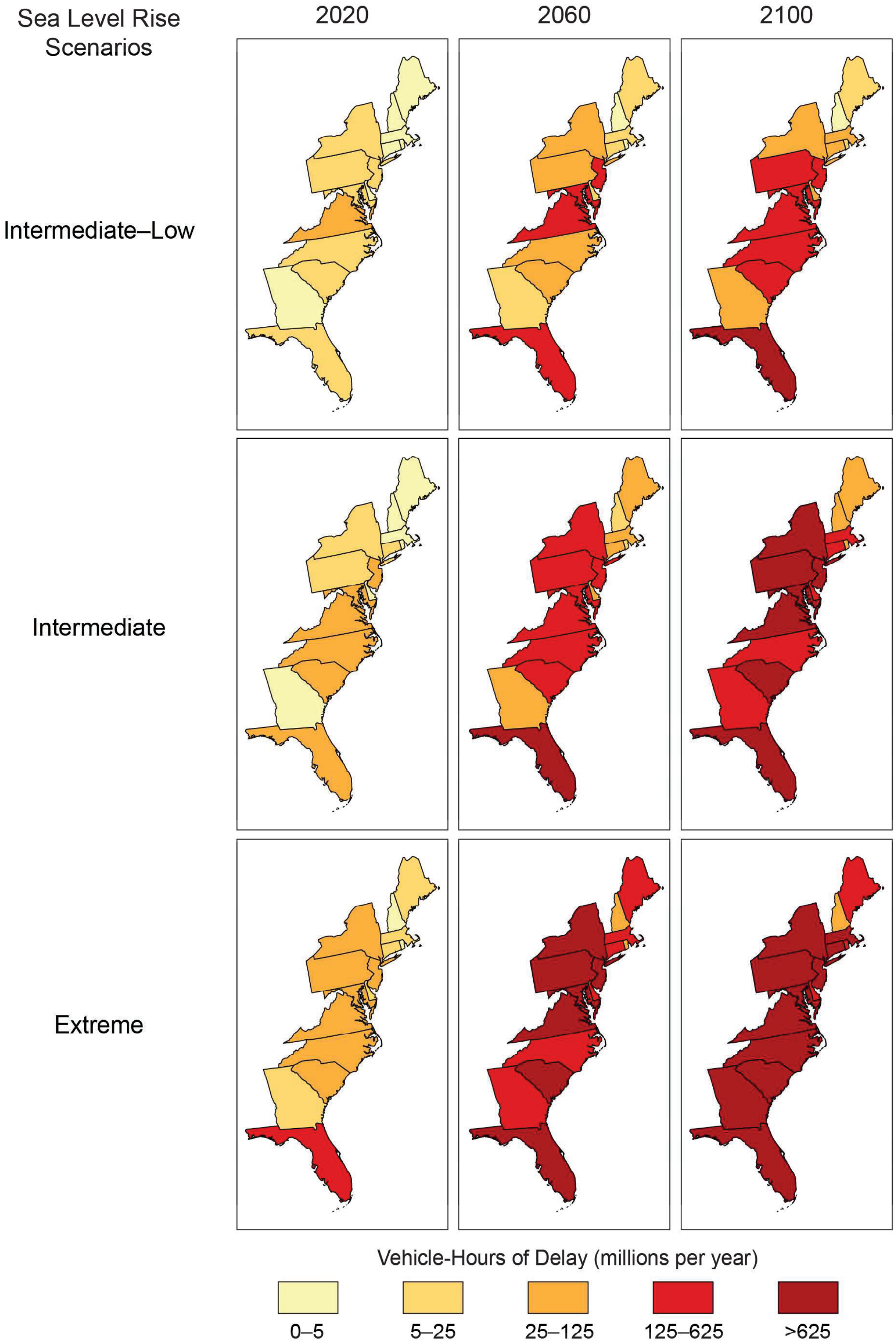

Figure 12.2: The figure shows annual vehicle-hours of delay for major roads (principal arterials, minor arterials, and major collectors) due to high tide flooding by state, year, and sea level rise scenario (from Sweet et al. 2017).[59] Years are shown using decadal average (10-year) values (that is, 2020 is 2016–2025), except 2100, which is a 5-year average (2096–2100). One vehicle-hour of delay is equivalent to one vehicle delayed for one hour. Source: Jacobs et al. 2018,[61] Figure 3, reproduced with permission of the Transportation Research Board.

precipitation increases transportation hazards from landslides and washouts.[50] In the western United States, large wildfires have increased and are likely to increase further in the future.[70] Debris flows, which consist of water, mud, and debris, are post-wildfire hazards that can escalate the vulnerability of transportation infrastructure to severe precipitation events[71] by blocking culverts and inundating roads.[72]

Rising Temperature Risks

The frequency of summer heat waves has increased since the 1960s, and average annual temperatures have increased over the past three decades; these temperature changes are projected to continue to increase in the future.[41] Across the United States, record-breaking summer temperatures and heat waves have immediate and long-term impacts on transportation. Through the urban heat island effect, heat events may become hotter and longer in cities than in the surrounding rural and suburban areas (Ch. 11: Urban).

High temperatures can stress bridge integrity.[4,5] Extreme temperatures cause frequent and extended delays to passenger and freight rail systems and air traffic when local safe operating guidelines are exceeded.[4,6] Rail tracks expand and weaken, sometimes even bend, under extreme heat.[73] Air transport is sensitive to extreme heat because hotter air makes it more difficult for airplanes to generate lift (the force required for an airplane to take flight), especially at higher elevations, requiring weight reductions and/or longer takeoff distances that may require runway extensions.[74,75]

Heat also compromises worker and public safety. Temperature extremes cause vehicles to overheat and tires to shred, while buckled roadway joints can send vehicles airborne.[76,77] Elevated temperature, combined with increased salinity and humidity, accelerates deterioration in bridges and roads constructed with concrete.[78,79] Higher ambient temperatures and extreme heat events can negatively impact pavement performance and, in turn, increase costs due to material upgrades to accommodate higher temperatures; these costs are only modestly reduced by less frequent maintenance.[12] For example, fixing pavement distress caused by a 2011 heat wave and drought cost the Texas Department of Transportation (DOT) $26 million (dollar year unspecified).[80]

Heat waves and drought require state DOTs to allocate resources to repair damaged pavement. For example, Virginia DOT has dedicated crews who quickly repair roads during extreme heat events.[81] Protocols that govern worker safety limit construction during heat waves[3,76,82] and result in lost productivity.[83] Increased cooling needed to alleviate passenger discomfort and cargo overheating[84] can cause mechanical failures and reduced service, as well as greater greenhouse gas emissions.

An additional 20–30 days per year with temperatures exceeding 90°F (32°C) are projected in most areas by mid-century under a higher scenario (RCP8.5), with increases of 40–50 days in much of the Southeast.[41] In the United States, 5.8 million miles of paved roads are susceptible to increased rutting, cracking, and buckling when sustained temperatures exceed 90°F.[85] Climate change is anticipated to increase the current $73 billion in temperature-induced railway delay costs by $25–$60 billion (in 2015 dollars, discounted at 3%).[6] Heat impacts to airports are expected to increase in the future[74] and, in some cases, are the most critical vulnerability for a region.[86]

It is possible that projected warmer conditions could have some positive effects. Milder winters will lengthen the shipping season in northern inland ports, including the Great Lakes and the Saint Lawrence Seaway.[87,88] The

reduction of snow and icing events in southern regions will likely benefit transportation safety, because snow has a significantly higher vehicle accident risk than rainfall.[66,82] Damage to bridges and roads caused by potholes and frost heaves costs hundreds of millions of dollars annually,[4] and changing winter conditions will likely alleviate expenditures in some regions but amplify expenditures in others.[12] However, thawing and freezing rain events may reduce some of the winter maintenance savings. The Alaska Department of Transportation and Public Facilities is anticipating significant challenges due to the effects of warming temperatures on roadways, and it may see increased costs in anti-icing measures in areas that previously rarely had mid-winter thawing and freezing rain.[89]

Key Message 2

Impacts to Urban and Rural Transportation

Extreme events that increasingly impact the transportation network are inducing societal and economic consequences, some of which disproportionately affect vulnerable populations. In the absence of intervention, future changes in climate will lead to increasing transportation challenges, particularly because of system complexity, aging infrastructure, and dependency across sectors.

Urban Transportation Network

The urban transportation network can be highly complex and in high demand, with populations relying on many modes of transportation across air, water, and land. U.S. urban highways tend to accommodate more than double the vehicle miles traveled compared to rural highways.[90] A high percentage of the urban population relies on public transit,[91] with greatest usage in the Northeast.[92]

The urban setting tends to amplify climate change impacts, such as flooding, on the performance of the transportation network. Combined sewer and storm sewer systems used in many cities are often not designed to withstand the capacity demand currently experienced during heavy rainfall events or rising high tides (Ch. 11: Urban). This situation is becoming increasingly problematic with more frequent localized flooding, leading to more frequent travel disruptions for commuters, travelers, and freight.[93,94] The effect is compounded in cities with older infrastructure, such as Philadelphia, Miami, Chicago, and Charleston.[94,95,96,97]

Interdependencies among transportation and other critical infrastructure sectors (such as energy) introduce the risk of significant cascading impacts on the operational capacity of the transportation urban network (Ch. 17: Complex Systems, KM 1 and 3). For example, in December 2017, Atlanta's Hartsfield–Jackson International Airport was shut down for nearly 11 hours due to a catastrophic power outage, which caused the cancellation of 1,400 flights.

In an urban environment, there is a greater chance of transportation network redundancy during an extreme weather event. For example, in the New York City metro area after Superstorm Sandy, additional bus service was able to partially compensate for flooded subway and commuter tunnels.[98,99,100] Walking also serves as an essential backstop in urban environments. For cargo, if a portion of a railway suffers damage due to a future flood event, there may be opportunities to redirect freight to highways and/or waterways.

Disruptions to the transportation network during extreme weather events can disproportionately affect low-income people, older adults, people with limited English proficiency, and other vulnerable urban populations.

These populations have fewer mobility options, reduced access to healthcare, and reduced economic ability to purchase goods and services to prepare for and recover from events.[101,102,103]

With growing suburban populations, there is increasing dependence on a variety of transportation systems. For example, in Boston, almost 130,000 people take commuter rail daily.[104] During extreme events, workers in suburban areas often cannot commute to urban offices, leading to economic losses. Evidence of this is seen from the transportation interruptions resulting from storms such as Hurricane Irene, which impacted Philadelphia and New York City, and Superstorm Sandy, which impacted the Northeast Corridor.[105] Telecommuting can mitigate some of these impacts, but a notable component of suburban areas and their economies remains dependent on a reliable transportation system.

Rural Transportation Network

The rural transportation network may lack redundancy, which increases the social and economic dependence on each road and affects agriculture, manufacturing, tourism, and more. Flood events are prolific and exemplify the dependency that rural areas have on their transportation networks. This dependence is illustrated by the 2013 flooding in Boulder, Colorado, where a 200-year flood event (an event having about a 0.5% chance of occurring in a given year) resulted in 485 miles of damaged or destroyed roadways and 1,100 landslide and hillslope failures that cut off many rural towns for weeks.[106,107] In 2016, more than 10 inches of rain caused widespread flooding throughout eastern Iowa and isolated towns along the Cedar River.[108] In 2017, Hurricane Irma entirely cut off road access to the Florida Keys.

Relative to urban areas, rural areas have fewer options for funding the maintenance and rebuilding of roads.[109] During recovery efforts, rural areas have logistical challenges that include the ability to transport the needed construction materials and a dependency on freight networks to support the population.[110] Rural communities face rebuilding challenges that often take additional time and inflict long-term economic damage to residents and local economies.[111]

Resilience Planning

Many federal, state, and municipal agencies have developed frameworks and tools to assess climate change transportation resilience, in some cases in response to legislative and policy actions. There has been an emergence of climate resilience design guidelines for new transportation infrastructure, as well as considerations of climate change in infrastructure regulations and permitting. For example, the City of New York and the Port Authority of New York and New Jersey have issued guidance that instructs project teams on how to incorporate future climate data into capital expenditures.[112,113] However, it is not only large, urban areas that are addressing potential climate impacts to transportation systems. Municipalities in states such as Wisconsin, North Carolina, Mississippi, and Tennessee are including considerations for climate vulnerability and adaptation in long-range planning.[114]

Challenges remain in the development of resilience plans. In the urban environment, issues such as predicting the potential costs of repair and identifying the rippling disruptions are required to inform the investment decision of implementing mitigation strategies.[115] Compared to urban areas, rural areas sometimes struggle to create structures and justify resilience plans, which are both cost effective and address the potential risk from climate change. As illustrated by vulnerable areas such as the

Gulf Coast, increasing storm intensity suggests the need for investments in both improved emergency management planning techniques[116] and increased transportation redundancy. Similarly, in rural mountain areas, where increased precipitation can lead to landslides, the cost of preventive actions may be difficult to justify given the uncertainty of occurrence.[117]

Key Message 3

Vulnerability Assessments

Engineers, planners, and researchers in the transportation field are showing increasing interest and sophistication in understanding the risks that climate hazards pose to transportation assets and services. Transportation practitioner efforts demonstrate the connection between advanced assessment and the implementation of adaptive measures, though many communities still face challenges and barriers to action.

Motivation for Vulnerability Assessments

Transportation practitioners are increasingly invested in addressing climate risks, as evidenced in more numerous and diverse assessments of transportation sector vulnerabilities across the United States. These assessments address the direct and indirect reactions to extreme events, funding opportunities and technical assistance and expertise, and the improved availability of climate model outputs. Federal agencies and others have made funding and tools available to evaluate asset-specific and system-wide vulnerabilities in the transportation sector.[118,119,120] For example, the Federal Highway Administration (FHWA) funded 24 pilot studies between 2010 and 2015; these pilots road-tested and advanced frameworks for conducting vulnerability assessments.[120,121,122,123] In the airport sector, the Transportation Research Board supported research and developed guidance for climate risk assessments,[124] adaptation strategies, the integration of climate risk into airport management systems, and benefit–cost analyses. A review of more than 60 vulnerability assessments published between 2012 and 2016 was conducted for this chapter. Results of this review are summarized below and depicted in Figure 12.3.

Vulnerability Assessments Synopsis

Transportation vulnerabilities to climate change can be very different from one location to another. Examining the commonality and differences among place-based vulnerability assessments provides insights into what communities feel are their greatest vulnerabilities. While early climate risk assessment relied on readily available indicators (such as location, elevation, and condition) to screen assets for exposure to climate risks, asset owners and operators have increasingly conducted more focused studies of particular assets that consider multiple climate hazards and scenarios in the context of asset-specific information, such as design lifetime. Of the 60 studies included in the online version of Figure 12.3, roadways were the most commonly assessed asset, followed by bridges and rail. Most assessments used geospatial data to identify vulnerabilities; more sophisticated assessments utilized models as well (for example, Transportation Engineering Approaches to Climate Resiliency, GC2, and the Massachusetts Department of Transportation).[125,126,127] Building on guidance from the FHWA and others,[28] some agencies engaged stakeholders to ground-truth and/or fortify their results.[128]

Most studies focus on multiple climate stressors, including both chronic issues (such as sea level rise) and extreme events (such as flooding, storm surge, and extreme heat). Sea level rise and flooding are the most commonly assessed individual stressors. Although combined risks are rarely assessed, sea level rise and storm surge are sometimes considered together. The majority of

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Transportation Vulnerability and Risk Assessments

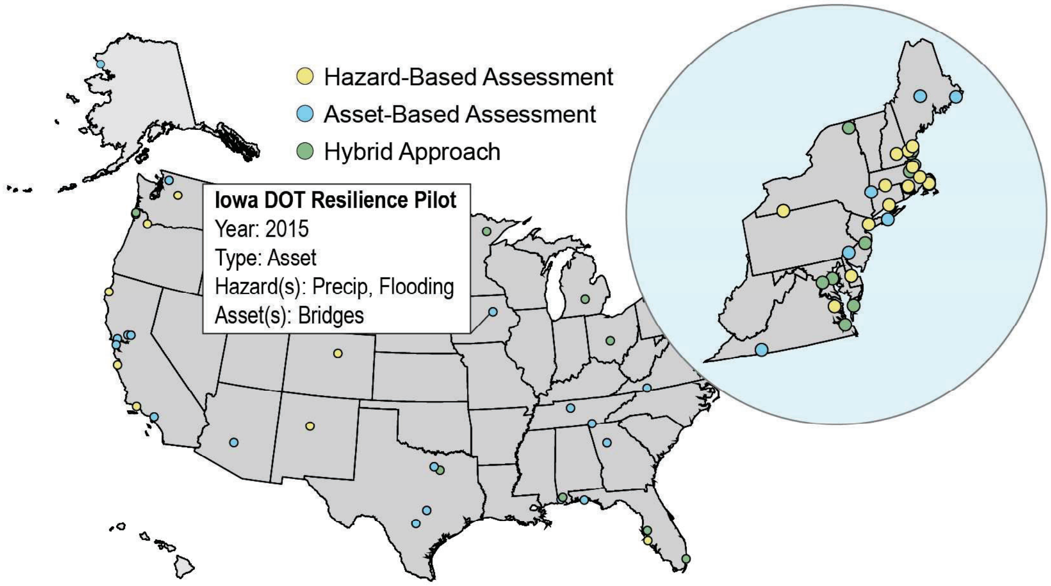

Figure 12.3: This figure shows transportation vulnerability and/or risk assessments from 2012 to 2016 by location. Cumulatively, these vulnerability assessments elucidate national-scale vulnerabilities and progress. Data for the U.S. Caribbean region were not available. See the online version of this map at http://nca2018.globalchange.gov/chapter/12#fig-12-3 to access the complete set of vulnerability and risk assessments. Sources: ICF and U.S. Department of Transportation.

assessments consider only asset-specific vulnerabilities and not transportation system-wide vulnerabilities or vulnerabilities influencing or arising from interdependencies with other sectors (such as water or energy).

The few studies that quantify the costs and benefits from adaptation primarily focus on single assets, rather than the system, and do not quantify both the direct and indirect (such as labor costs) economic costs of transportation system disruptions. The U.S. DOT Hampton Roads Climate Impact Quantification Initiative, currently underway, seeks to demonstrate a replicable approach to considering these costs.[129]

Implementation of Resilience Measures

Proactive implementation of resilience measures is still limited. Resilient solutions for transportation facilities vary greatly depending on the climate stressor, the specifics of a given site, and the availability of funding for implementation (see "Three Case Studies of Resilience Measures for Highway Facilities"). Building the business case for adaptation and aligning the required long-term investments with existing time frames for decision-making is difficult.[3,130,131] Uncertainties associated with projections of future climate hazards in specific geographic locations[130,132,133] and the lack of specific, detailed adaptation strategies[134] make assessment more complicated. However, in the wake of extreme events, some transportation agencies implemented resilience measures to withstand similar events in the future.

Future changes to and uncertainties about transportation technologies and transportation-related behaviors complicate agencies' ability to assess the adaptive capacity of transportation systems, their ability to withstand and recover from a disruption, and opportunities for cost-effective risk mitigation strategies (such as workplace telecommuting policies).

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Case Study: Three Case Studies of Resilience Measures for Highway Facilities

In Florida, storm surges overwashing US 98 on Okaloosa Island undermined the highway foundation during Hurricane Ivan in 2004 and then again during other tropical storms in 2005. To prevent damage from overwash in the future, the Florida Department of Transportation installed buried erosion protection along the edge of the road. FHWA's analysis found that this proactive countermeasure was economically justified when it was done in 2006 and, further, that the benefit–cost ratio will quadruple over the next 50 years as sea levels continue to rise.[135]

Shore Road in Brookhaven, New York, is experiencing wave-induced bank erosion during storms. The road elevation is about 2 feet higher than the typical high tide today, and a recent study determined that constructing a coastal marsh can protect the roadway for decades at a low cost while enhancing ecosystems. At a later point, the town could increase the elevation of the road and install more expensive sheet pile walls or rock revetments if needed.[136]

In 2013 in Colorado, precipitation following wildfires caused massive debris flows that overwhelmed culverts and damaged US 24 (see Figure 12.4 for similar case). Recognizing the seriousness of this type of impact, engineering tools driven by future climate simulations were used to evaluate changing wildfire-induced debris flows and precipitation risks to culverts when rebuilding a similar highway (US 34). The best approach identified was to quickly adapt a culvert if and when a wildfire occurs in that watershed, with the goal of upsizing the structure before a rainfall event can cause it to fail. Adapting every culvert to account for wildfire risk would be prohibitively costly, especially given the high uncertainty and low probability that any particular culvert will be impacted by a wildfire over its service life.[72]

Flood Impacts on Colorado Highway

Figure 12.4: Flooding events can result in serious damage to road infrastructure. Here, debris flow covers US Highway 14 (Poudre Canyon) after the High Park Fire in 2012. Photo credit: Justin Pipe, Colorado Department of Transportation.

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Opening Image Credit

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Traceable Accounts

Process Description

We sought an author team that could bring diverse experiences and perspectives to the chapter, including some who have participated in prior national-level assessments within the sector. All are experts in the field of climate adaptation and transportation infrastructure. The team represents geographic expertise in the Northeast, Mid-Atlantic, South, Central, and Western regions, including urban and rural as well as coastal and inland perspectives. Team members come from the public (federal and city government and academia) and private sectors (consulting and engineering), with practitioner and research backgrounds.

The chapter was developed through technical discussions of relevant evidence and expert deliberation by the report authors at several workshops and teleconferences and via email exchanges. The authors considered inputs and comments submitted by the public, the National Academies of Sciences, Engineering, and Medicine, and federal agencies. For additional information on the overall report process, see Appendix 1: Process. The author team also engaged in targeted consultations with transportation experts during multiple listening sessions.

Because the impacts of climate change on transportation assets for the United States and globally have been widely examined elsewhere, including in the Third National Climate Assessment (NCA3),[137] this chapter addresses previously identified climate change impacts on transportation assets that persist nationally, with a focus on recent literature that describes newly identified impacts and advances in understanding. Asset vulnerability and impacts are of national importance because there are societal and economic consequences that transcend regional or subregional boundaries when a transportation network fails to perform as designed; a chapter focus is the emerging understanding of those impacts. Further, place-based, societally relevant understanding of transportation system resilience has been strongly informed by numerous recent local and state assessments that capture regionally relevant climate impacts on transportation and collectively inform national level risks and resilience. The chapter synthesizes the transportation communities' national awareness of and readiness for climate threats that are most relevant in the United States.

Key Message 1

Transportation at Risk

A reliable, safe, and efficient U.S. transportation system is at risk from increases in heavy precipitation, coastal flooding, heat, wildfires, and other extreme events, as well as changes to average temperature (*high confidence*). Throughout this century, climate change will continue to pose a risk to U.S. transportation infrastructure, with regional differences (*high confidence*).

Description of evidence base

Global mean sea level has risen since 1900 and is expected to continue to rise.[2] High tide flooding is increasing and is projected to continue increasing.[1] The peak storm surge levels are expected to rise more than the rise in sea level; models show that if the depth of storm flooding today is A and the rise in sea level between now and a future occurrence of an identical storm is B, then the

resulting future storm surge depths can be greater than A + B.[52] The U.S. roads and bridges in the coastal floodplain[49] are vulnerable today, as storms are repeatedly causing damage.[50,53,54,138] Sea level rise is also projected to impact ports,[57] airports,[58] and roads.[63,64,65] High tide flooding currently makes some roads impassable due to flooding[60,61] and is very likely to increase transportation disruptions in the future.[61]

In most parts of the United States, heavy precipitation is increasing in frequency and intensity, and more severe precipitation events are anticipated in the future.[25] Inland transportation infrastructure is highly vulnerable to intense rainfall and flooding.[3,25,66,67,69,139] In the western United States, large wildfires have increased and are likely to increase in the future,[70] escalating the vulnerability of transportation infrastructure to severe precipitation events.[71,72]

The frequency of summer heat waves has increased since the 1960s, and average annual temperatures have increased over the past three decades; these temperature changes are projected to continue to increase in the future.[41] Warming temperatures have increased costs[81] and reduced the performance of roads,[80] bridges,[4,5] railways,[4,5,6] and air transport.[3,74,86] Future temperature increases are projected to reduce infrastructure lifetime[78,79,122] and increase road costs.[12] Milder winters will likely lengthen the shipping season in northern inland ports,[87,88] benefit transportation safety,[42,43,44,66,82] and reduce winter maintenance.[4,12,45] In Alaska, however, permafrost thawing will damage roads[46] and increase the cost of roads (Ch. 26: Alaska).

Major uncertainties

Peer-reviewed literature on climate impacts to some assets is limited. Most literature addresses local- or regional-scale issues. Uncertainty in the ranges of climate change projection leads to challenges to quantifying impacts on transportation assets, which have long lifetimes.

Impacts to transportation infrastructure from climate change will depend on many factors, including population growth, economic demands, policy decisions, and technological changes. How these factors, with their potential compounding effects, as well as the impacts of disruptive or transformative technologies (such as automated vehicles or autonomous aerial vehicles), will contribute to transportation performance in the future is poorly understood.

The relationship among increases in large precipitation events and flood-induced infrastructure damage is uncertain because multiple factors (including land use, topography, and even flood control) impact flooding.[140,141,142,143] Hirsch and Ryberg (2012)[144] found limited evidence of increasing global mean carbon dioxide concentrations resulting in increasing flooding in any region of the United States. Archfield et al. (2016)[145] found that flood changes to date are fragmented and that a climate change signal on flood changes was not yet clear.

Description of confidence and likelihood

There is *very high confidence* that sea level rise and increases in flooding during coastal storms and astronomical high tides will lead to damage and service reductions with coastal bridges, roads, rails, and ports.

There is *high confidence* that heavy precipitation events have increased in intensity and frequency since 1901 (with the largest increase seen in the Northeast); this trend is projected to continue.[25] There is *medium confidence* that precipitation increases will lead to surface and rail transit delays

in urban areas. There is *medium confidence* that flood-induced damages to roads and bridges will increase.

Rising temperatures and extreme heat (*high confidence*) will damage pavement and increase railway and air transit delays. However, the actual magnitude of those impacts will depend on technological advancements and policy decisions about design and operations.

Key Message 2

Impacts to Urban and Rural Transportation

Extreme events that increasingly impact the transportation network are inducing societal and economic consequences, some of which disproportionately affect vulnerable populations (*high confidence*). In the absence of intervention, future changes in climate will lead to increasing transportation challenges, particularly because of system complexity, aging infrastructure, and dependency across sectors (*high confidence*).

Description of evidence base

The Key Message is largely supported by observation and empirical evidence that is well documented in the gray (non-peer-reviewed) literature and recent government reports. Because this is an important emerging area of research, the peer-reviewed scientific literature is sparse. Hence, much of the supporting materials for this Key Message are descriptions of impacts of recent events provided by news organizations and government summaries.

Many urban locations have experienced disruptive extreme events that have impacted the transportation network and led to societal and economic consequences. Louisiana experienced historic floods in 2016 that disrupted all modes of transportation and caused adverse impacts on major industries and businesses due to the halt of freight movement and employees' inability to get to work.[146] The 2016 floods that affected Texas from March to June resulted in major business disruption due to the loss of a major transportation corridor.[147] In 2017, Hurricane Harvey affected population and freight mobility in Houston, Texas, when 23 ports were closed and over 700 roads were deemed impassable.[148] Consequences of extreme events can be magnified when events are cumulative. The 2017 hurricanes impacting the southern Atlantic and Gulf Coasts and Puerto Rico created rising freight costs because freight carriers had to deal with poor traveling conditions, an unreliable fuel stock, and limited exports for the return trip.[149,150] Low-income populations have been linked to differences in perceived risks associated with an extreme event, in how they respond, and in their ability to evacuate or relocate.[151] Delays in evacuations can potentially lead to significant transportation delays, affecting the timeliness of first responders and evacuations. National- and local-level decision-makers are considering strategies during storm recovery and its aftermath to identify and support vulnerable populations to ensure transportation and access to schools, work, and community services (for example, the 2016 Baton Rouge flood event).

Similar to the urban and suburban scenarios, rural areas across the country have also experienced disruptions and impacts from climate events. Hurricane Irene resulted in the damage or destruction of roads throughout New England, resulting in small towns being isolated throughout the region.[152] Similarly, Hurricane Katrina devastated rural community infrastructure across the Gulf

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Coast, which resulted in extended periods of isolation and population movement.[153] Lesser-known events are also causing regular impacts to rural communities, such as flood events in 2014 in Minnesota and in 2017 throughout the Midwest, which impacted towns for months due to damaged road infrastructure.[154,155]

Although flooding events and hurricanes receive significant attention, other weather-based events cause equal or greater impacts to rural areas. Landslide events have isolated rural communities by reducing them to single-road access.[156,157] Extreme heat events combined with drought have resulted in increases in wildfire activity that have impacted rural areas in several regions. The impacts of these wildfire events include damage to infrastructure both within rural communities and to access points to the communities.[158]

As documented, rural communities incur impacts from climate events that are similar to those experienced in urban and suburban communities. However, rural and isolated areas experience the additional concerns of recovering from extreme events with fewer resources and less capacity.[111] This difference often results in rural communities facing extended periods of time with limited access for commercial and residential traffic.

Major uncertainties

Realized societal and economic impacts from transportation disruptions vary by extreme event, depending on the intensity and duration of the storm; pre-storm conditions, including cumulative events; planning mechanisms (such as zoning practices); and so on. In addition, a combination of weather stressors, such as heavy precipitation with notable storm surge, can amplify effects on different assets, compounding the societal and economic consequences. These amplifications are poorly understood but directly affect transportation users. Interdependencies among transportation and other lifeline sectors can also have significant impacts on the degree of consequences experienced. These impacts are also poorly understood.

Description of confidence and likelihood

There is *medium to high confidence* that the urban setting can amplify heat.[159] There is also *medium to high confidence* that transportation networks are impacted by inland and coastal flooding.[70] There is *medium confidence* that socioeconomic conditions are strongly related to a population's resilience to extreme events.[151]

There is *high confidence* that impacts to the transportation network from extreme events are inducing societal and economic consequences, some of which disproportionately affect vulnerable populations (*medium confidence*). In the absence of intervention, projected changes in climate will likely lead to increasing transportation challenges as a result of system complexity, aging infrastructure with hundreds of billions of dollars in rehabilitation backlogs,[13] and dependency across sectors.

Key Message 3

Vulnerability Assessments

Engineers, planners, and researchers in the transportation field are showing increasing interest and sophistication in understanding the risks that climate hazards pose to transportation assets and services (*very high confidence*). Transportation practitioner efforts demonstrate the connection between advanced assessment and the implementation of adaptive measures, though many communities still face challenges and barriers to action (*high confidence*).

Description of evidence base

Chapter authors reviewed more than 60 recently published vulnerability assessments (details and links available through the online version of Figure 12.3) conducted by or for states and localities. The research approach involved internet searches, consultations with experts, and leveraging existing syntheses and compilations of transportation-related vulnerability assessments. The authors cast a broad net to ensure that as many assessments as possible were captured in the review. The studies were screened for a variety of metrics (for example, method of assessment, hazard type, asset category, vulnerability assessment type, economic analysis, and adaptation actions), and findings were used to inform the conclusions reached in this section.

Major uncertainties

Most of the literature and the practitioner studies cited for Key Message 3 were gray literature, which is not peer-reviewed but serves the purpose of documenting the state of the practice. This section was not an assessment of the science (that is, the validity of individual study results was not assessed) but surveyed how transportation practitioners are assessing and managing climate impacts. The conclusions are not predicated on selection of or relative benefits of specific modeling or technological advances.

Practitioners' motivations underlying changes in the state of the practice were derived from information in the studies and from cited literature. The authors of this section did not survey authors of individual vulnerability studies to determine their situation-specific motivations.

Description of confidence and likelihood

There is *high confidence* regarding the efforts of state and local transportation agencies to understand climate impacts through assessments like those referenced in Figure 12.3. There is *medium confidence* in the reasons for delay in implementing resilience measures and the motivations for vulnerability assessments. There is no consensus on how emerging transportation technologies will develop in the coming years and how this change will affect climate mitigation, adaptation, and resilience.

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2013 Status of the Nation's Highways, Bridges, and Transit:

Conditions & Performance

U.S. Department
of Transportation

Federal Highway
Administration

Federal Transit
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REPORT TO CONGRESS

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Abbreviations

AADT	average annual daily traffic
AADTT	average annual daily truck traffic
AARP	American Association of Retired Persons
AASHTO	American Association of State Highway and Transportation Officials
ACE	Altamont Commuter Express
ACS	American Community Survey
AC Transit	Alameda-Contra Costa Transit District
ADA	Americans with Disabilities Act of 1990
ADT	annual daily traffic; average daily traffic
ADTT	average daily truck travel
AEO	Annual Energy Outlook
APTA	American Public Transportation Association
APU	auxiliary power unit
ATDM	active transportation and demand management
ATM	Active Traffic Management
ATS	alternative transportation systems
BAB	Build America Bond
BAC	blood alcohol content
BART	San Francisco Bay Area Rapid Transit District
Bay Area	San Francisco Bay Area
B/C	benefit-cost
BCR	benefit-cost ratio
BIRM	Bridge Inspector’s Reference Manual
BLM	Bureau of Land Management
BPI	Bid Price Index
C-TIP	Cross-Town Improvement Project
C&P	Conditions and Performance
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CATA	Central Arkansas Transit Authority
CATS	Charlotte Area Transit System
CDOT	Connecticut Department of Transportation
CFR	U.S. Code of Federal Regulations
CFS	Commodity Flow Survey
CMAQ	Congestion Mitigation and Air Quality
CM-GC	construction manager-general contractor
CMTA	Capital Metropolitan Transportation Authority
CNG	compressed natural gas

CO_2	carbon dioxide
Combo	combination (trucks)
CPI	Consumer Price Index
CRR	Corps Recreation Roads
CTA	Chicago Transit Authority
CTE	Center for Transportation and the Environment
DART	Dallas Area Rapid Transit
DB	design-build
DBB	design-bid-build
DC	direct current
DHS	Department of Homeland Security
DO	directly operated
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOT	Department of Transportation
DR	Demand Response
DRM	directional route mile
DTS	City and County of Honolulu Department of Transportation Services
EDC	Every Day Counts
EERE	Efficiency and Renewable Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FAF	Freight Analysis Framework
FARS	Fatality Analysis Reporting System
FCEB	fuel cell electric bus
FH	Forest Highways
FHWA	Federal Highway Administration
FLH	Office of Federal Lands Highway
FLHP	Federal Lands Highway Program
FLMA	Federal Land Management Agency
FMCSA	Federal Motor Carrier Safety Administration
FPM	freight performance measures
FS	USDA Forest Service
FTA	Federal Transit Administration
FWS	Fish and Wildlife Service
FY	fiscal year
g/dL	gram per deciliter
GARVEE	Grant Anticipation Revenue Vehicle
GCRTA	The Greater Cleveland Regional Transit Authority
GDP	gross domestic product
GHG	greenhouse gas
GIS	geographic information system
GPS	global positioning system
GRS-IBS	geosynthetic reinforced soil integrated bridge system
HART	Hillsborough Area Regional Transit Authority
HBP	Highway Bridge Program
HERS	Highway Economic Requirements System
HERS-ST	HERS State Version

HFCS	Highway Functional Classification System
HPMS	Highway Performance Monitoring System
HPMS-AP	HPMS Analytical Process
HR	Heavy Rail
HSIP	Highway Safety Improvement Program
HTF	Highway Trust Fund
HUD	Department of Housing and Urban Development
IC	intelligent compaction
IDAS	ITS Deployment Analysis System
INVEST	Infrastructure Voluntary Evaluation Sustainability Tool
IRI	International Roughness Index
IRR	Indian Reservation Roads
ISIP	Intersection Safety Implementation Plan
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
IT	Island Transit
ITS	intelligent transportation system(s)
King County Metro	King County Department of Transportation
KT	Kenosha Transit
LACMTA	Los Angeles County Metropolitan Transportation Authority
LNG	liquefied natural gas
LR	Light Rail
LPG	liquefied petroleum gas
MAP-21	Moving Ahead for Progress in the 21st Century Act
MARTA	Metropolitan Atlanta Rapid Transit Authority
MATA	Memphis Area Transit Authority
MB	Motorbus
MBTA	Massachusetts Bay Transportation Authority
MDT	Miami-Dade Transit
ME-PDG	Mechanistic Empirical Pavement Design Guide
Metra	Northeast Illinois Regional Commuter Railroad Corporation
METRO	Bi-State Development Agency; Metropolitan Transit Authority of Harris County, Texas
Metrolink	Southern California Regional Rail Authority
MIR	Military Installation Roads
MOU	Memorandum of Understanding
MOVES	Motor Vehicle Emission Simulator
mpg	miles per gallon
MPO	metropolitan planning organization
MR&R	maintenance, repair, and replacement; maintenance, repair, and rehabilitation
MSA	Metropolitan Statistical Area
MTA	Mass Transit Account; Maryland Transit Administration
MTA LIRR	MTA Long Island Rail Road
MTA-MNCR	Metro-North Commuter Railroad Company
MTS	San Diego Metropolitan Transit System
MTSI	mean time to service interruption
MUNI	San Francisco Municipal Railway
MUTCD	Manual of Uniform Traffic Control Devices
NAVC	Northeast Advanced Vehicle Consortium
NASS GES	National Automotive Sampling System General Estimates System
NBER	National Bureau of Economic Research

NBI	National Bridge Inventory
NBIAS	National Bridge Investment Analysis System
NBIS	National Bridge Inspection Standards
NCHRP	National Cooperative Highway Research Program
NCTD	North County Transit District
NEPA	National Environmental Policy Act
NFS	National Forest System
NFSR	National Forest System Roads
NFCBP	National Fuel Cell Bus Program
NFT Metro	Niagara Frontier Transportation Authority
NHCCI	National Highway Construction Cost Index
NHPP	National Highway Performance Program
NHS	National Highway System
NHTS	National Household Travel Survey
NHTSA	National Highway Traffic Safety Administration
NICTD	Northern Indiana Commuter Transportation District
NJ TRANSIT	New Jersey Transit Corporation
NLCS	National Landscape Conservation System
NNEPRA	Northern New England Passenger Rail Authority
NO_x	nitrogen oxide
NORTA	New Orleans Regional Transit Authority
NPS	National Park Service
NTD	National Transit Database
NTPP	Nonmotorized Transportation Pilot Program
NWRS	National Wildlife Refuge System
NYCT	MTA New York City Transit
O&M	operations and maintenance
OF&E	Other Freeway and Expressway
OMB	Office of Management and Budget
OPA	Other Principal Arterial
P3	Public-Private Partnership
PAB	Private Activity Bond
PATCO	Port Authority Transit Corporation
PATH	Port Authority Trans-Hudson Corporation
PCJPB	Peninsula Corridor Joint Powers Board
PEL	Planning and Environmental Linkages
PENNDOT	Pennsylvania Department of Transportation
PLDR&T	public lands development roads and trails
PLHD	Public Lands Highway Discretionary Program
PM-10	particulate matter of 10 microns in diameter or smaller
PMT	passenger miles traveled; person miles of travel
Port Authority	Port Authority of Allegheny County
PRHTA	Puerto Rico Highway and Transportation Authority
PRP	park roads and parkways
PSR	Present Serviceability Rating; Pavement Serviceability Rating
PT	purchased transportation
PV	passenger vehicle
RAIRS	Rail Accident/Injury Reporting System
Reclamation	Bureau of Reclamation

Recovery Act	American Recovery and Reinvestment Act
RMRTD	Rio Metro Regional Transit District
RR	Refuge Roads
RSDP	Roadway Safety Data Program
RTA	Regional Transportation Authority
RTD	Denver Regional Transportation District
RVD	recreation visitor days
Sacramento RT	Sacramento Regional Transit District
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SEPTA	Southeastern Pennsylvania Transportation Authority
SGR	state of good repair
SHRP2	Strategic Highway Research Program 2
SHSP	Strategic Highway Safety Plan
SIB	State Infrastructure Bank
SIRTOA	Staten Island Rapid Transit Operating Authority
SQC	Synthesis, Quantity, and Condition
SRTS	Safe Routes to School
S/TIP	State/Transportation Improvement Program
ST	Central Puget Sound Regional Transit Authority
STAA	Surface Transportation Assistance Act of 1982
STP	Surface Transportation Program
STRAHNET	Strategic Highway Network
STURAA	Surface Transportation and Uniform Relocation Assistance Act of 1987
SU	single-unit (truck)
TEA-21	Transportation Equity Act for the 21st Century
TEAM	Transit Electronic Award Management
TERM	Transit Economic Requirements Model
TEU	Twenty-foot equivalent unit
TIFIA	Transportation Infrastructure and Finance Innovation Act
TIGER	Transportation Investment Generating Economic Recovery
TMC	traffic management center
TMG	Traffic Monitoring Guide
TRB	Transportation Research Board
TRDF	Texas Research and Development Foundation
TriMet	Tri-County Metropolitan Transportation District of Oregon
TRIP	Transit in the Parks
TRI-Rail	South Florida Regional Transportation Authority
TTI	Texas Transportation Institute
TVT	Traffic Volume Trends
UCR	Urban Congestion Report
UN	United Nations
UPT	unlinked passenger trips
U.S.	United States
USACE	U.S. Army Corps of Engineers
USAGE	United States Applied General Equilibrium
U.S.C.	United States Code
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
UTA	Utah Transit Authority

UZA	urbanized area
VII	Vehicle Infrastructure Integration
VIUS	Vehicle Inventory and Use Survey
VMR	Valley Metro Rail, Inc.
VMS	variable message signs
VMT	vehicle miles traveled
VRE	Virginia Railway Express
VRM	vehicle revenue mile
V/SF	volume/service flow
VSL	value of a statistical life; variable speed limit
VTA	Santa Clara Valley Transportation Authority
VTTS	value of travel time savings
WMA	warm mix asphalt
WMATA	Washington Metropolitan Area Transit Authority
WSDOT	Washington Department of Transportation
ZEBA	Zero Emission Bay Area

Introduction

This is the tenth in a series of combined documents prepared by the U.S. Department of Transportation (DOT) to satisfy requirements for reports to Congress on the condition, performance, and future capital investment needs of the Nation's highway and transit systems. This report incorporates highway, bridge, and transit information required by 23 U.S.C. §503(b)(8), as well as transit system information required by 49 U.S.C. §308(e). Beginning in 1993, the Department combined two separate existing report series that covered highways and transit to form this report series; prior to this, 11 reports had been issued on the condition and performance of the Nation's highway systems, starting in 1968. Five separate reports on the Nation's transit systems' performance and conditions were issued beginning in 1984.

This *2013 Status of the Nation's Highways, Bridges, and Transit: Conditions and Performance* report to Congress (C&P report) draws primarily on 2010 data, which reflect funds from the American Recovery and Reinvestment Act of 2009 (Recovery Act) (Pub.L. 111–5). The 2010 C&P Report, transmitted on March 15, 2012, was based primarily on 2008 data.

In assessing recent trends, many of the exhibits presented in this report present statistics for the 10 years from 2000 to 2010. Other charts and tables cover different time periods depending on data availability and years of significance for particular data series. The prospective analyses presented in this report generally cover the 20-year period ending in 2030.

Report Purpose

This document is intended to provide decision makers with an objective appraisal of the physical conditions, operational performances, and financing mechanisms of highways, bridges, and transit systems based both on the current state of these systems and on their projected future state under a set of alternative future investment scenarios. This report offers a comprehensive, data-driven background context to support the development and evaluation of legislative, program, and budget options at all levels of government. It also serves as a primary source of information for national and international news media, transportation associations, and industry.

This C&P report consolidates conditions, performance, and financial data provided by States, local governments, and public transit operators to provide a national-level summary. Some of the underlying data are available through the U.S. DOT's regular statistical publications. The future investment scenario analyses are developed specifically for this report and provide national-level projections only.

Report Organization

This report begins with an Executive Summary that highlights key findings of the overall report, which is followed by Chapter Overviews that summarize the key findings in each individual chapter.

The main body of the report is organized into four major sections. The six chapters in Part I, "Description of Current System," contain the core retrospective analyses of the report. Chapters 2 through 6 each include separate highway and transit sections discussing each mode in depth. This structure is intended to accommodate report users who may primarily be interested in only one of the two modes. The Introduction to Part I provides background information on the Recovery Act and performance management.

- **Chapter 1** provides information on household travel and highway freight movement.
- **Chapter 2** describes recent trends in highway, bridge, and transit system characteristics.
- **Chapter 3** depicts the current physical conditions of highways, bridges, and transit systems.
- **Chapter 4** discusses issues relating to the safety of highways and transit.
- **Chapter 5** presents information on various aspects of the current system performance for highways and transit, including sustainability and operational performance.
- **Chapter 6** discusses highway and transit revenue sources and expenditure patterns for all levels of government.

The four chapters in Part II, "Investment/Performance Analysis," contain the core prospective analyses of the report, including 20-year future capital investment scenarios. The Introduction to Part II provides critical background information and caveats that should be considered while interpreting the findings presented in Chapters 7 through 10.

- **Chapter 7** projects the potential impacts of different levels of future highway, bridge, and transit capital investment on the future performance of various components of the system.
- **Chapter 8** describes selected capital investment scenarios in more detail and relates these scenarios to the current levels of capital investment for highways, bridges, and transit.
- **Chapter 9** provides supplemental analysis relating to the primary investment scenarios, comparing the future investment scenario findings to previous reports and discussing scenario implications.
- **Chapter 10** discusses how the future highway and transit investment scenarios would be affected by changing some of the underlying technical assumptions.

Part III, "Special Topics," explores some topics related to the primary analyses in the earlier sections of the report.

- **Chapter 11** examines the transportation systems serving Federal and Tribal lands.
- **Chapter 12** describes the FHWA Center for Accelerating Innovation.
- **Chapter 13** discusses FTA's National Fuel Cell Bus Program.

The report also contains three technical appendices that describe the investment/performance methodologies used in the report for highways, for bridges, and for transit. A fourth appendix describes ongoing research activities and identifies potential areas for improvement in the data and analytical tools used to produce the analyses contained in this report.

Highway Data Sources

Highway conditions and performance data are derived from the Highway Performance Monitoring System (HPMS), a cooperative data/analytical effort dating from the late 1970s that involves the Federal Highway Administration (FHWA) and State and local governments. The HPMS includes a statistically drawn sample of more than 100,000 highway sections containing data on current physical and operating characteristics, as well as projections of future travel growth on a section-by-section basis. All HPMS data are provided to FHWA through State DOTs from existing State or local government databases or transportation plans and programs, including those of metropolitan planning organizations.

The HPMS data are collected in accordance with the *Highway Performance Monitoring System Field Manual for the Continuing Analytical and Statistical Database.* This document is designed to create a uniform and consistent database by providing standardized collection, coding, and reporting instructions for the various data items. The FHWA reviews the State-reported HPMS data for completeness, consistency, and adherence to reporting guidelines. Where necessary, and with close State cooperation, data may be adjusted to improve

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uniformity. The HPMS data also serve as a critical input to other studies that are cited in various parts of this report, such as the Texas Transportation Institute's *2010 Urban Mobility Report.*

State and local finance data are derived from the financial reports provided by the States to FHWA in accordance with *A Guide to Reporting Highway Statistics.* These are the same data used in compiling the annual *Highway Statistics* report. The FHWA adjusts these data to improve completeness, consistency, and uniformity. Highway safety performance data are drawn from the Fatality Analysis Reporting System (FARS).

Bridge Data Sources

The FHWA collects bridge inventory and inspection data from the States annually and incorporates the data into the National Bridge Inventory (NBI). The NBI contains information from all bridges covered by the National Bridge Inspection Standards (Title 23, Code of Federal Regulations, Part 650) located on public roads throughout the United States and Puerto Rico. Inventory information for each bridge includes descriptive identification data, functional characteristics, structural design types and materials, location, age and service, geometric characteristics, navigation data, and functional classifications; conditions information includes inspectors' evaluations of the primary components of a bridge, such as the deck, superstructure, and substructure. Most bridges are inspected once every 24 months. The archival NBI data sets represent the most comprehensive uniform source of information available on the conditions and performance of bridges located on public roads throughout the United States.

Transit Data Sources

Transit data are derived from the National Transit Database (NTD) and transit agency asset inventories. The NTD provides comprehensive data on the revenue sources, capital and operating expenses, basic asset holdings, service levels, annual passenger boardings, and safety data of the more than 700 urban and 1,500 rural transit operators that receive annual funding support through the Federal Transit Administration's (FTA's) Section 5307 (Urbanized Area) and Section 5311 (Rural Area) Formula Programs. However, with the exception of fleet vehicle holdings (where NTD provides comprehensive data on the composition and age of transit fleets), NTD does not provide the data required to assess the current physical condition of the Nation's transit infrastructure.

To meet this need, FTA collects transit asset inventory data from a sample of the Nation's largest rail and bus transit operators. In direct contrast to the data in either NTD or HPMS—which local and State funding grantees are required to report to FTA and FHWA, respectively, and which are subject to standardized reporting procedures—the transit asset inventory data used to assess current transit conditions have been provided to FTA in response to direct requests submitted to grantees and have not been subject to any reporting requirements. Although there are no current reporting requirements or reporting standards for asset inventory data, the Moving Ahead for Progress in the 21st Century Act (MAP-21) transportation bill requires that grantees submit this information to NTD. Once rules for collecting this data are formalized in regulation and grantees start submitting it, FTA will have much better data on which to base its forecasts.

In recent practice, data requests have mostly been made to the Nation's 20 to 30 largest transit agencies because these agencies account for roughly 85 percent of the Nation's total transit infrastructure by value. Considering the slow rate of change in transit agency asset holdings over time (excluding fleet vehicles and major expansion projects), FTA has requested these data from any given agency only every 3 to 5 years. The asset inventory data collected through these requests document the age, quantity, and replacement costs of the grantees' asset holdings by asset type. The nonvehicle asset holdings of smaller operators have been estimated using a combination of (1) the fleet-size and facility-count data reported to NTD and (2) the

actual asset age data of a sample of smaller agencies that respond to previous asset inventory requests. This method of obtaining asset data has served FTA well in the past (and the quality of the reported data has improved over time), but the accuracy and comprehensiveness of FTA's estimates of current asset conditions and capital reinvestment needs will benefit from the standardized reporting requirements to be developed as per the requirements of MAP-21.

Other Data Sources

This report also relies on data from a number of other sources. For example, the National Household Travel Survey (NHTS) collected by the FHWA provides information on the characteristics, volume, and proportion of passenger travel across all modes of transportation. Information on freight activity is collected by the Census Bureau through the Commodity Flow Survey, and then merged with other data in FHWA's Freight Analysis Framework.

Investment/Performance Analytical Procedures

The earliest versions of the reports in this combined series relied exclusively on engineering-based estimates for future investment/performance analysis, which considered only the costs incurred by transportation agencies. This approach failed to adequately consider another critical dimension of transportation programs, such as the impacts of transportation investments on the costs incurred by the users of the transportation system. Executive Order 12893, *Principles for Federal Infrastructure Investments,* dated January 1994, directs each executive department and agency with infrastructure responsibilities to base investments on ". . . systematic analysis of expected benefits and costs, including both quantitative and qualitative measures . . ." New approaches have been developed to address the deficiencies in earlier versions of this report and to meet this Executive Order. The analytical tools now used in this report have added an economic overlay to the development of future investment scenarios.

The highway investment scenarios presented in this report are developed in part from the Highway Economic Requirements System (HERS), which uses benefit-cost analysis to optimize highway investment. The HERS model quantifies user, agency, and societal costs for various types and combinations of improvements, including travel time and vehicle operating, safety, capital, maintenance, and emissions costs. Bridge investment scenario estimates are developed from the National Bridge Investment Analysis System (NBIAS) model. Unlike earlier bridge models (and similar to HERS), NBIAS incorporates benefit-cost analysis into the bridge investment/performance evaluation.

The transit investment analysis is based on the Transit Economic Requirements Model (TERM). The TERM consolidates older engineering-based evaluation tools and introduces a benefit-cost analysis to ensure that investment benefits exceed investment costs. TERM identifies the investments needed to replace and rehabilitate existing assets, improve operating performance, and expand transit systems to address the growth in travel demand.

The HERS, NBIAS, and TERM models have not yet evolved to the point where direct multimodal analysis is possible. While the three models all utilize benefit-cost analysis, their methods for implementing this analysis are very different. The highway, transit, and bridge models are all based on separate databases that are very different from one another. Each model makes use of the specific data available for its part of the transportation system and addresses issues unique to each mode. For example, HERS assumes that when lanes are added to a highway, this causes highway user costs to fall, resulting in additional highway travel. Under this assumption, some of this increased traffic would be newly generated travel and some could be the result of travel shifting from transit to highways. However, HERS does not distinguish between different sources of additional highway travel. At present, there is no truly accurate method for predicting the impact

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that a given level of highway investment would have on the future performance of transit systems. Likewise, TERM's benefit-cost analysis assumes that some travel shifts from automobile to transit as a result of transit investments, but cannot project these investments' impact on highways.

In interpreting the findings of this report, it is important to recognize the limitations of these analytical tools and the potential impacts of different assumptions that have been made as part of the analysis. Appendix D and the Introduction to Part II both contain information critical to contextualizing the future investment scenarios, and these issues are also discussed in Q&A boxes located in Chapters 7 through 10.

Changes to C&P Report Scenarios from 2010 Edition

The selected capital investment scenarios presented in Chapter 8 are framed somewhat differently from those presented in the 2010 edition of the C&P report. While the transit scenario definitions have remained largely unchanged, the highway and bridge scenarios have been revised.

The 2010 C&P Report presented a single version of each highway and bridge scenario in Chapter 8, based on modeled projections of future vehicle miles of travel (VMT) for individual highway sections provided by the States to the HPMS. This edition includes some scenarios that assume lower future VMT growth based on the historic trend over the past 15 years; these alternative analyses are referred to as "Trend-Based" in this report.

The 2010 C&P Report introduced **Low Growth** and **High Growth** scenarios for transit, which are retained in this edition. The former is based on modeled transit ridership projections developed by Metropolitan Planning Organizations (MPOs), while the latter assumes higher future ridership based on the historic trend over the last 15 years.

The **Maintain Conditions and Performance** scenario for highways and bridges presented in the 2010 C&P Report used average speed and the economic bridge investment backlog as primary indicators. This edition instead targets average pavement roughness, average delay per VMT, and the average bridge sufficiency rating in defining this scenario.

The highway and bridge components of the **Intermediate Improvement** scenario presented in the 2010 C&P Report used the same annual growth in spending, based on HERS analysis. For this edition, the highway and bridge components were derived independently, with the bridge component based on achieving half of the improvement to average bridge sufficiency rating projected by NBIAS for the **Improve Conditions and Performance** scenario.

Cautionary Notes on Using This Report

In order to correctly interpret the analyses presented in this report, it is important to understand the framework in which they were developed and to recognize their limitations. This document is not a statement of Administration policy, and the future investment scenarios presented are intended to be illustrative only. **The report does not endorse any particular level of future highway, bridge, or transit investment.** It does not address what future Federal surface transportation programs should look like, or what level of future surface transportation funding can or should be provided by the Federal government, State governments, local governments, the private sector, or system users. Making recommendations on policy issues such as these would go beyond the legislative mandate for the report and would violate its objectivity. Outside analysts can and do make use of the statistics presented in the C&P report to draw their own conclusions, but any analysis attempting to use the information presented in this report to determine a target Federal program size would require a whole series of additional policy and technical assumptions that go well beyond what is reflected in the report itself.

The investment scenario estimates presented in this report are estimates of the performance that **could** be achieved with a given level of funding, not necessarily what **would** be achieved with it. The analytical tools used in the development of these estimates combine engineering and economic procedures, determining deficiencies based on engineering standards while applying benefit-cost analysis procedures to identify potential capital improvements to address deficiencies that may have positive net benefits. Although the models generally assume that projects are prioritized based on their benefit-cost ratios, that assumption deviates somewhat from actual patterns of project selection and funding distribution that occur in the real world. Consequently, the level of investment identified as the amount required to maintain a certain performance level should be viewed as **illustrative only**, and should not be considered a projection or prediction of actual condition and performance outcomes likely to result from a given level of national spending.

As in any modeling process, simplifying assumptions have been made to make analysis practical and to report within the limitations of available data. Because the ultimate decisions concerning highways, bridges, and transit systems are primarily made by their operators at the State and local levels, they have a much stronger business case for collecting and retaining detailed data on individual system components. The Federal government collects selected data from States and transit operators to support this report, as well as a number of other Federal activities, but these data are not sufficiently robust to make definitive recommendations concerning specific transportation investments in specific locations. Improvements are evaluated based on benefit-cost analysis, but not all external costs (such as noise pollution or construction-related loss of wildlife habitat) or external benefits (such as the productivity gains that may result from transportation improvements opening up markets to competition) are fully considered. Across a broad program of investment projects, such external effects may cancel each other; but, to the extent that they do not, the true "needs" may be either higher or lower than would be predicted by the models.

Recovery Act: Overview and Impacts

In February 2009, the American Recovery and Reinvestment Act authorized $48.1 billion for programs administered by the U.S. Department of Transportation (DOT). The U.S. DOT's broad recovery goals reflect those of the Recovery Act, primarily (1) creating and preserving jobs and promoting economic recovery and (2) investing in infrastructure that has long-term economic benefits. Supporting the former goal required that Recovery Act funds be spent quickly on projects that would contribute to the Federal government's larger efforts to promote economic recovery. Supporting the latter goal required that Recovery Act funds be invested in projects that provide long-term benefits for the Nation's transportation systems. Of most relevance to the transportation modes reflected in the C&P report are the $27.5 billion appropriated for programs administered by FHWA and $8.4 billion appropriated for programs administered by FTA. In addition, highway, bridge, and transit projects were eligible to compete for Office of the Secretary of Transportation's Supplemental Discretionary Grant for a National Surface Transportation System program, later referred to as the TIGER I program.

The short-term goal of the Recovery Act was to support jobs in the economy. The States and transit agencies were required to report the number of labor hours worked on projects supported by Recovery Act expenditures. Reported labor hours were converted to full-time job year equivalents by dividing hours worked by 2080 (40 hours multiplied by 52 weeks). Each job-year could reflect one person working full time for a whole year or two people working 6 months each. The "1201 (c) Report as of January 30, 2011" submitted to Congress in December 2011 indicated that the cumulative total number of jobs-years report for Recovery Act-funded highway and transit projects were 54,686 and 21,368, respectively. In addition to the direct jobs reported, jobs are also supported in industries that supply construction materials, transportation, and other services to the construction sector, referred to as indirect jobs. These were estimated to be 97,557

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Summary of Recovery Act Funding Received by DOT, by Appropriation Title

Operating Administration	Budget Authority ($Billions)	Program Name
Federal Highway Administration	27.5	Highway Infrastructure Investment
Federal Transit Administration	6.9	Transit Capital Assistance
	0.75	Capital Investment Grants
	0.75	Fixed Guideway Infrastructure Investment
Office of the Secretary of Transportation	1.5	Supplemental Discretionary Grants for a National Surface transportation System (TIGER)
Federal Aviation Administration	0.2	Facilities and Equipment
	1.1	Grants-in-Aid to Airports
Federal Railroad	1.3	Capital Grants to the National Railroad Passenger Corporation
	8.0	Capital Assistance for High Speed Rail Corridors
Maritime Administration	0.1	Assistance to Small Shipyards
Office of inspector General	0.02	Salaries and Expenses
Transportation Total	**48.12**	

Source: U.S. DOT American Recovery and Reinvestment Act of 2009, Pub.L. 111-5

for highways and 25,368 for transit. The wages earned from these jobs are spent to buy consumer goods and services, inducing jobs in other sectors. The total number of jobs (direct, indirect, induced) were estimated to be 195,325 for highways and 57,467.

The longer-term goal of the Recovery Act, which is more directly relevant to the C&P report, was to invest in infrastructure to produce long-term economic benefits. Through December 31, 2010, the Recovery Act had funded a total of 12,931 highway projects covering 41,840 miles of roadway. This included 7,632 pavement improvement projects (covering 33,340 miles), 421 pavement widening projects (covering 1,076 miles), and 173 new construction projects (covering 429 miles). Also included were 663 bridge replacement projects, 574 bridge improvement projects, and 61 new bridge construction projects. The Recovery Act also supported 970 projects (covering 3,775 miles) focused on safety or traffic management, 1,645 transportation enhancement projects (covering 2,194 miles), and 792 projects (covering 1,027 miles) involving other types of highway improvements. These investments will yield economic benefits through their lifetimes; having addressed these specific needs in the short term will allow a greater share of future investment to be targeted at other system needs.

Consistent with the operation of the regular Federal-aid program funds as a reimbursement program, the Recovery Act funds were obligated to specific projects up front, but the actual transfer of Federal dollars to the grant recipients occurs more gradually over the life of the projects. Through the end of 2010, approximately $17.3 billion of Recovery Act funding had been expended for highway projects, and approximately $3.5 billion had been expended for transit projects. Consequently the 2010 conditions and performance data presented in this report do not yet fully reflect the results of the Recovery Act investments. Recovery Act investments will continue to impact future financial data, as well as condition and performance data.

Because the financial statistics presented in the C&P report are cash-based, the Recovery Act funding is accounted for at the time that States and transit agencies are reimbursed, and appears in the revenue figures as support from Federal general funds. During 2010, $11.9 billion of funding appropriated under the Recovery Act funds were expended for highway purposes and $2.4 billion were expended for transit capital investments.

Q&A

What are the Implications of the Recovery Act for the C&P report?

The Recovery Act significantly affects the financial and other data presented in Part I of the C&P Report and the future investment scenarios in Part II. The Recovery Act impacts are particularly visible in the financial data presented in Chapter 6.

The financial data are presented on a cash basis, so that Recovery Act funding is not reflected in the year it was authorized or obligated, but instead in the year it was expended. Although $27.5 billion and $8.4 billion were authorized for highways and transit investments in 2009 and the deadline set for the obligation of these funds was September 30, 2010, only the funds that were actually expended in 2010 will show up in this report.

In 2010, the Recovery Act funded $11.9 billion of the expenditures for highways and $2.4 billion of the expenditures for transit. Since Recovery Act funding was not drawn from the user charges that support the Federal Highway Trust Fund, these amounts shows up as General Fund revenues, which reduces the national percentage of spending supported by user changes in 2010, relative to most previous years. States and transit agencies were given tight deadlines to obligate Recovery Act funding, and encouraged to select projects that could proceed quickly, in order to produce a short-term impact on employment, particularly in the construction industry. This influenced the types of projects selected and increased the National share of highway capital spending directed toward system rehabilitation spending significantly compared to recent years. Although the long-term effects of this shift are unclear, given a set program of planned and prioritized potential future investments, transportation agencies may shift the focus of their future investment toward other types of investments that did not receive significant amounts of funding from the Recovery Act. While not directly attributable to the Recovery Act, there has been some degree of slowdown in the spending rate from regular Federal highway and transit program funds in recent years compared to some earlier years.

Spending supported by the Recovery Act also impacts the conditions, safety, and performance data presented in Chapters 3, 4, and 5. However, the full effects of the Recovery Act are not yet reflected in the data, since some of the funds have not yet been expended. In addition, while projects are underway, they can have a temporary negative impact on system users (in terms of pavement condition, delays, etc.) until they are completed. Given the number of projects underway in 2010, this could have had an impact on the national-level statistics.

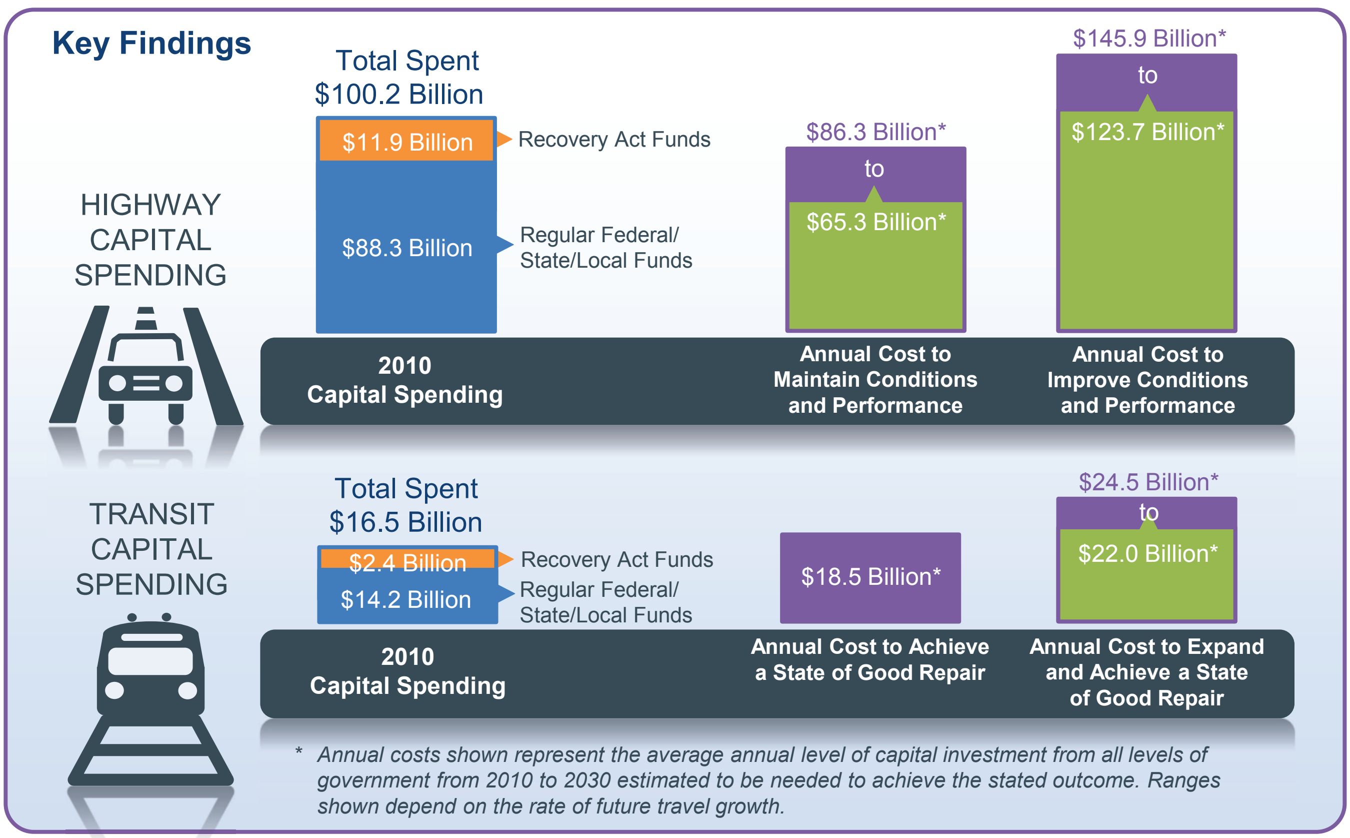
Caution should be taken in evaluating the scenario findings presented in Chapters 7 through 10 of this report given the impact of Recovery Act funding on spending in 2010, which was used as the base year for the 20-year scenarios presented. Sustaining spending at 2010 levels may prove more challenging than would be the case for a more typical base year. To emphasize this point, the scenario identified as “Sustain Current Spending” in previous C&P reports was renamed as “Sustain 2010 Spending” for this report.

Executive Summary

This edition of the C&P report is based primarily on data through the year 2010; consequently, the system conditions and performance measures presented should reflect effects of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), which authorized Federal highway and transit funding for Federal fiscal years 2005 through 2009 (and extended through fiscal year 2012), as well as some of the impact of the funding authorized under the American Recovery and Reinvestment Act of 2009 (Recovery Act). None of the impact of funding authorized under the Moving Ahead for Progress in the 21st Century Act (MAP-21) is reflected. In assessing recent trends, this report generally focuses on the 10-year period from 2000 to 2010. The prospective analyses generally cover the 20-year period ending in 2030; the investment levels associated with these scenarios are stated in constant 2010 dollars.

In 2010, all levels of government spent a combined $205.3 billion for highway-related purposes, of which $11.9 billion was a direct impact of the Recovery Act. All levels of government spent a combined $54.3 billion for transit-related purposes, including $2.4 billion of expenditures supported by one-time funding under the Recovery Act.

The average annual capital investment level needed to maintain the conditions and performance of highways and bridges at 2010 levels through the year 2030 is projected to range from $65.3 billion to $86.3 billion per year, depending on the future rate of growth in vehicle miles traveled (VMT). Improving the conditions and performance of highways and bridges by implementing all cost-beneficial investments would cost an estimated $123.7 billion to $145.9 billion per year. (Note that these projections are much lower than those presented in the 2010 C&P report, driven in part by an 18 percent reduction in highway construction prices



between 2008 and 2010). In 2010, all levels of government spent a combined $100.2 billion for capital improvements to highways and bridges.

Bringing existing transit assets up to a state of good repair would require an annualized investment level of $18.5 billion through the year 2030. The estimated combined costs associated with accommodating future increases in transit ridership and addressing system preservation needs when it is cost-beneficial to do so, would range from $22.0 billion to $24.5 billion per year. In 2010, all levels of government spent a combined $16.5 billion for transit capital improvements.

Highlights: Highways and Bridges

Extent of the System

- The Nation's road network includes more than 4,083,768 miles of public roadways and more than 604,493 bridges. In 2010, this network carried almost 2.985 trillion vehicle miles traveled (VMT).
- The 1,007,777 miles of Federal-aid highways (25 percent of total mileage) carried 2.525 trillion VMT (85 percent of total travel) in 2010.
- While the 162,698 miles on the National Highway System (NHS) make up only 4 percent of total mileage, the NHS carried 1.305 trillion VMT in 2010, just under 44 percent of total travel.
- The 47,182 miles on the Interstate System carried 0.731 trillion VMT in 2010, constituting a bit over 1 percent of mileage and just over 24 percent of total VMT.

Highway System Terminology

"Federal-aid Highways" are roads that are generally eligible for Federal funding assistance under current law. (Note that certain Federal programs do allow the use of Federal funds on other roadways.)

The "National Highway System" (NHS) includes those roads that are most important to interstate travel, economic expansion, and national defense. It includes the entire Interstate System. MAP-21 directed that the NHS system be expanded. The statistics presented for 2010 reflect the NHS as it existed then. The 20-year scenarios have been adjusted to approximate the NHS after expansion.

Spending on the System

- All levels of government spent a combined $205.3 billion for highway-related purposes in 2010. About half of total highway spending ($100.2 billion) was for capital improvements to highways and bridges; the remainder included expenditures for physical maintenance, highway and traffic services, administration, highway safety, and debt service.
- In nominal dollar terms, highway spending increased by 67.3 percent between 2000 and 2010; adjusting for inflation this equates to a 35.9 percent increase. Highway capital expenditures increased by 63.4 percent between 2000 and 2010, equaling a 36.6 percent increase when adjusted for inflation.
- The portion of total highway capital spending funded by the Federal government increased from 42.6 percent in 2000 to 44.3 percent in 2010. The average annual increase in Federally funded highway capital outlay grew by 5.4 percent per year over this period, compared to a 4.7 annual increase in capital spending funded by State and local governments.

Constant Dollar Conversions for Highway Expenditures

This report uses the Federal Highway Administration's (FHWA's) National Highway Construction Cost Index (NHCCI) and its predecessor, the Composite Bid Price Index (BPI), for inflation adjustments to highway capital expenditures and the Consumer Price Index (CPI) for adjustments to other types of highway expenditures.

- The composition of highway capital spending shifted from 2000 to 2010, particularly from 2008 to 2010, which was partially attributable to the Recovery Act. The percentage of highway capital spending directed toward system rehabilitation rose from 52.7 percent in 2000 to 59.9 percent in 2010. Over the same period, the percentage directed toward system enhancement rose from 9.9 percent to 12.8 percent, while the percentage directed toward system expansion fell from 37.4 percent to 27.4 percent.

Highway Capital Spending Terminology

This report splits highway capital spending into three broad categories. "System Rehabilitation" includes resurfacing, rehabilitation, or reconstruction of existing highway lanes and bridges. "System Expansion" includes the construction of new highways and bridges and the addition of lanes to existing highways. "System Enhancement" includes safety enhancements, traffic control facilities, and environmental enhancements.

Conditions and Performance of the System

- Work is under way to establish metrics and data collection systems to capture information on attaining sustainable transportation systems, both in terms of fostering livable communities and advancing environmental sustainability.

Highway Safety Has Improved

- The annual number of highway fatalities was reduced by 21.6 percent between 2000 and 2010, dropping from 41,945 to 32,885. The fatality rate per 100 million VMT declined from 1.53 in 2000 to 1.11 in 2010.
- Between 2000 and 2010, the number of pedestrians killed by motor vehicle crashes decreased by 10.1 percent, from 4,763 to 4,282, and the number of pedalcyclists (such as bicyclists) killed has decreased almost 10.8 percent, from 693 to 618. While these are positive trends, they also reflect that less progress has been made in reducing nonmotorist fatalities than in reducing overall highway fatalities.
- The number of traffic-related injuries decreased by almost 32 percent from 3.1 million to 2.1 million between 2000 and 2010. The injury rate per 100 million VMT declined from 112 in 2000 to 71 in 2010.

Pavement Conditions Have Improved in Many Areas

- The percentage of VMT on NHS pavements with "good" ride quality rose from 48 percent in 2000 to 60 percent in 2010. The share of VMT on NHS pavements with "acceptable" ride quality increased from 91 percent to 93 percent.
- The percentage of Federal-aid Highway VMT on pavements with "good" ride quality rose from 42.8 percent in 2000 to 50.6 percent in 2010, while the share of VMT on pavements with "acceptable" or better ride quality declined from 85.5 percent to 82.0 percent.
- The improvement in the percentage of VMT on pavements with "good" ride quality has not been uniform across the system. For lower-volume urban roadways classified as urban minor arterials, or urban collectors, the percent of VMT on pavements with "good" ride quality and "acceptable" ride quality both declined between 2000 and 2010. This result appears consistent with a change in philosophy among

Pavement Condition Terminology

This report uses the International Roughness Index (IRI) as a proxy for overall pavement condition. Pavements with an IRI value of less than 95 inches per mile are considered to have "good" ride quality. Pavements with an IRI value less than or equal to 170 inches per mile are considered to have "acceptable" ride quality. (Based on these definitions "good" is a subset of the "acceptable" category.) These metrics are typically VMT weighted, so the report refers to the percent of VMT on pavements with good ride quality. (Note that the NHS pavement statistics presented in this report are based on calendar year data, consistent with the annual Highway Statistics publication; in other DOT publications presented on a fiscal year basis, these calendar 2010 NHS statistics appear as Fiscal Year 2011 data.)

many transportation agencies leading them to move away from a simple strategy of addressing assets on a "worst first" basis toward more comprehensive strategies aimed at targeting investment where it will benefit the most users.

Bridge Conditions Have Improved

- Based directly on bridge counts, the share of NHS bridges classified as structurally deficient declined from 6.0 percent in 2000 to 5.1 percent in 2010. Over this period, the share classified as functionally obsolete declined from 17.7 percent to 16.3 percent, so the total share classified as deficient declined from 23.7 percent to 21.4 percent.
- Weighted by deck area, the share of NHS bridges classified as structurally deficient declined from 8.7 percent in 2000 to 8.3 percent in 2010. Over this period, the share classified as functionally obsolete declined from 22.0 percent to 20.3 percent, so the total share classified as deficient declined from 30.7 percent to 28.7 percent.
- Systemwide, based on bridge counts, the share of bridges classified as structurally deficient declined from 15.2 percent to 11.7 percent from 2000 to 2010, the functionally obsolete share declined from 15.5 percent to 14.2 percent, and the total percentage of deficient bridges declined from 30.7 percent to 25.9 percent.
- The reductions in bridge deficiencies have not been uniform across the system. The share of rural interstate bridges classified as structurally deficient rose from 4.0 percent in 2000 to 4.5 percent in 2010; over the same period, the share of urban collector bridges classified as functionally obsolete was not reduced below the 2000 level of 28.1 percent.

Bridge Condition Terminology

Bridges are considered "structurally deficient" if significant load-carrying elements are found to be in poor or worse condition due to deterioration and/or damage, or the adequacy of the waterway opening provided by the bridge is determined to be extremely insufficient to the point of causing intolerable traffic interruptions due to high water. That a bridge is deficient does not imply that it is likely to collapse or that it is unsafe.

Functional obsolescence is a function of the geometrics (i.e., lane width, number of lanes on the bridge, shoulder width, presence of guardrails on the approaches, etc.) of the bridge in relation to the geometrics required by current design standards. As an example, a bridge designed in the 1930s would have shoulder widths in conformance with the design standards of the 1930s, but could be deficient relative to current design standards, which are based on different criteria and require wider bridge shoulders to meet current safety standards. The magnitude of these types of deficiencies determines whether a bridge is classified as "functionally obsolete."

These classifications are often weighted by bridge deck area, in recognition of the fact that bridges are not all the same size and, in general, larger bridges are more costly to rehabilitate or replace to address deficiencies. They are also sometimes weighted by annual daily traffic (ADT).

Future Capital Investment Scenarios – Systemwide

The scenarios that follow pertain to spending by all levels of government combined for the 20-year period from 2010 to 2030 (reflecting the impacts of spending from 2011 through 2030); the funding levels associated with all of these analyses are stated in constant 2010 dollars. Rather than assuming an immediate jump to a higher (or lower) investment level, each of these analyses assume that spending will grow by a uniform annual rate of increase (or decrease) in constant dollar terms using combined highway capital spending by all levels of government in 2010 as the starting point. As noted in the Introduction, caution should be taken in evaluating the scenario findings, given the impact of the Recovery Act funding on 2010 spending.

Sustain 2010 Spending Scenario

- The **Sustain 2010 Spending scenario** assumes that capital spending by all levels of government is sustained in constant dollar terms at the 2010 level ($100.2 billion systemwide) through 2030.
- At this level of spending, the average sufficiency rating for the Nation's bridges is projected to improve from 81.7 to 84.1 (on a scale of 0 to 100).
- Assuming a higher forecast-based future VMT growth (of 1.85 percent per year), average pavement ride quality on Federal-aid highways is projected to improve by 11.5 percent while average delay per VMT on Federal-aid highways worsens by 1.9 percent. Assuming lower trend-based VMT growth (of 1.36 percent per year), average pavement ride quality is projected to improve by 17.7 percent, while average delay improves by 7.8 percent.
- **Note that 2010 capital spending was supplemented by one-time funding under the Recovery Act, which would make it more challenging to sustain this level of spending in the future.**

Highway Investment/Performance Analyses

In order to provide an estimate of the costs that might be required to maintain or improve system performance, this report includes a series of investment/performance analyses that examine the potential impacts of alternative levels of future combined investment levels by all levels of government on highways and bridges for different subsets of the overall system.

Drawing upon these investment/performance analyses, a series of illustrative scenarios were selected for further exploration and presentation in more detail. The scenario criteria were applied separately to the Interstate System, the NHS, all Federal-aid highways, and the overall road system.

Recognizing that one of the major factors influencing future highway investment needs will be future travel demand, two sets of illustrative scenarios are presented for Federal-aid Highways and the overall system. One set incorporates travel forecasts provided by the States for individual highway sections (averaging to 1.85 percent growth per year), while the other assumes lower travel growth based on a continuation of national trends over the last 15 years (1.36 percent growth per year).

Maintain Conditions and Performance Scenario

- The **Maintain Conditions and Performance scenario** assumes that capital investment gradually changes in constant dollar terms over 20 years to the point at which selected measures of future conditions and performance in 2030 are maintained at 2010 levels.
- The average annual level of investment associated with this scenario is $86.3 billion systemwide assuming higher future VMT growth and $65.3 billion systemwide assuming lower future VMT growth.
- The annual investment levels for both versions of this systemwide scenario fall below the base year (2010) spending level. In previous editions of this report, the estimated costs of this scenario have typically been higher than base year spending, under most or all alternative versions of the scenario presented.

Improve Conditions and Performance Scenario

- The **Improve Conditions and Performance scenario** assumes that capital investment gradually rises to the point at which all potential highway and bridge investments that are estimated to be cost-beneficial (i.e., those with a benefit-cost ratio of 1.0 or higher) could be funded by 2030.
- Assuming higher future VMT growth, the average annual level of systemwide investment associated with this scenario is $145.9 billion. This is 45.7 percent higher than actual 2010 spending; a gap that could be closed if spending rose by 3.46 percent per year faster than the rate of future inflation.
- Assuming lower future VMT growth brings the annual cost of this systemwide scenario down to $123.7 billion, 23.4 percent higher than 2010 spending; a 1.96 percent annual increase in constant dollar spending would be sufficient to close this gap.
- The **State of Good Repair benchmark** represents the subset of this scenario that is directed toward addressing deficiencies of existing highway and bridge assets. The average annual investment level associated with this benchmark is $78.3 billion, assuming higher future VMT growth, and $72.9 billion, assuming lower future VMT growth.

Intermediate Improvement Scenario

- The highway component of the **Intermediate Improvement scenario** assumes that combined spending gradually rises to a point at which potential highway investments with a benefit-cost ratio of 1.5 or higher can be implemented; the bridge component represents the cost of achieving half of the gains in bridge sufficiency computed under the **Improve Conditions and Performance scenario**.
- The average annual level of systemwide investment associated with this scenario is $111.9 billion (11.7 percent higher than 2010 spending, which was 10.8 percent higher than 2008 spending due to the Recovery Act), assuming higher future VMT growth, and $93.9 billion (6.3 percent lower than 2010 spending), assuming lower future VMT growth.

Highlights: Transit

Extent of the System

- Of the transit agencies that submitted data to the National Transit Database (NTD) in 2010, 728 provided service to urbanized areas and 1,582 provided service to rural areas. Urban agencies operated 612 bus systems, 587 demand response systems, 18 heavy rail systems, 30 commuter rail systems, and 33 light rail systems. There were also 70 transit vanpool systems, 20 ferryboat systems, 5 trolleybus systems, 3 automated guideway systems, 3 inclined plane systems, and 1 cable car system.
- Bus and heavy rail modes continue to be the largest segments of the industry, providing 35.6 percent and 51.6 percent of all transit trips, respectively. Commuter rail supports a relatively high share of passenger miles (20.0 percent). Light rail is the fastest-growing rail mode (with passenger miles growing at 5.0 percent per year between 2000 and 2010) but it still provides only 4.1 percent of transit passenger miles. Vanpool growth during that period was 10.3 percent per year, with vanpools accounting for only 2.1 percent of all transit passenger miles.
- Urban transit operators reported 9.9 billion unlinked passenger trips on 3.9 billion vehicle revenue miles. Rural transit operators reported 123 million unlinked passenger trips on 570 million vehicle revenue miles.

Bus, Rail, and Demand Response: Transit Modes

Public transportation is provided by several different types of vehicles that are used in different operational *modes*. The most common is *fixed-route bus* service, which uses different sizes of rubber-tired buses that run on scheduled routes. *Commuter bus* service is similar but uses over-the-road buses and runs longer distances between stops. *Bus rapid transit* is high-frequency bus service that emulates light rail service. *Publicos and jitneys* are small owner-operated buses or vans that operate on less-formal schedules along regular routes.

Larger urban areas are often served by one or more varieties of *fixed-guideway* (rail) service. These include *heavy rail* (often running in subway tunnels) which is primarily characterized by third-rail electric power and exclusive dedicated guideway. Extended urban areas may have *commuter rail*, which often shares track with freight trains and usually uses overhead electric power (but may also use diesel power). *Light rail* systems are common in large- and medium-sized urban areas; they feature overhead electric power and run on track that is entirely or in part on city streets that are shared with pedestrian and automobile traffic. *Streetcars* are small light rail systems, usually with only one or two cars per train. *Cable cars*, *trolley buses*, *monorail*, and *automated guideway* systems are less-common rail variants.

Demand response transit service is usually provided by vans, taxicabs, or small buses that are dispatched to pick up passengers upon request. This mode is mostly used to provide *paratransit* service as required by the Americans with Disabilities Act. They do not follow a fixed schedule or route.

Spending on the System

- All levels of government spent a combined $54.3 billion to provide public transportation and maintain transit infrastructure. Of this, 26.1 percent was system-generated revenue, of which most came from

passenger fares. 19 percent of revenues came from the Federal government while the remaining funds came from State and local sources.

- Public transit agencies spent $16.6 billion on capital investments in 2010. Annually authorized Federal funding made up 26.6 percent of these capital expenditures. One-time funds from the Federal American Recovery and Reinvestment Act provided another 14.5 percent.
- Federal funding is primarily targeted for capital assistance; however, Federal funding for operating expenses at public transportation agencies has increased from 19 percent of all Federal funding in 2000 to 35 percent in 2010. Virtually all of the increase is due to the 2004 change making "preventative maintenance" eligible for reimbursement from 5307 grant funds. Maintenance is an operating expense. Meanwhile, farebox recovery ratios, representing the share of operating expenses that come from passenger fares, have remained close to the 2000 value of 35.5 percent throughout this period.
- Recent investments in system expansion have been adequate to keep pace with ridership growth (the average number of passengers per vehicle has not increased). Furthermore, continuing these investment levels will support projected growth in demand that falls between the low- and high-growth projections in this report. Investments in system preservation, however, still fall short of current and projected needs.

Federal Transit Funding Urban and Rural

Federal Transit Administration (FTA) Urbanized Area Formula Funds are apportioned to *urbanized areas* (UZAs), as defined by the Census Bureau. UZAs in this report were defined by the 2000 census. Data from the 2010 census will be used in the 2013 apportionment and beyond. Each UZA has a designated recipient, usually a Metropolitan Planning Organization (MPO) or large transit agency, which then sub-allocates FTA funds in its area according to local policy. In small urban and rural areas, FTA apportions funds to the State, which allocates them according to State policy. Indian tribes receive their funds directly. All funds then become available, on a reimbursement basis, through application to the FTA.

Conditions and Performance of the System

Transit Remains Safe

- There has been no significant increase in the rate of transit fatalities since 2004. Excluding suicides, that fatality rate hovers around one fatality for each 250 million passenger miles traveled (0.4 per 100 million).
- In 2010, one in four transit-related fatalities was classified as a suicide. In 2002, the rate was just one in 13. The rate of suicides on transit facilities has gone up every year since 2005.

Some Aspects of System Performance Have Improved

- Between 2000 and 2010, transit agencies have provided substantially more service. The annual rate of growth in route miles ranged from 0.4 percent for heavy rail to 6.0 percent for light rail. This has resulted in 21 percent more route miles available to the public.
- Between 2000 and 2010, the number of annual service miles per vehicle (vehicle productivity) increased steadily and the average number of miles between breakdowns (mean distance between failures) decreased by 14 percent. Thus, transit operators are getting more use out of their vehicles.

Unlinked Passenger Trips, Passenger Miles, Route Miles, and Revenue Miles

Unlinked passenger trips (UPT), also called boardings, count every time a person gets on an in-service transit vehicle. Each transfer to a new vehicle or route is considered another unlinked trip, so a person's commute to work may count as more than one trip if that person transferred between routes.

Passenger miles traveled (PMT) simply count how many miles a person travels. UPT and PMT are both commonly used measures of transit *service consumed*.

Directional route miles (DRM) measure the number of miles of transit route available to customers. They are directional because each direction counts separately; thus, a one-mile-out and one-mile-back bus route would be two DRM. *Vehicle Revenue Miles* (VRM) count the miles of revenue service, and are typically much greater than the DRM because many trips are taken over each route (and each DRM). These are commonly used measures of *transit service provided*.

- Growth in service offered was nearly in accordance with growth in service consumed. In spite of steady growth in route miles and revenue miles, average vehicle occupancy levels did not decrease. Passenger miles traveled grew at a 1.6-percent annual pace while the number of trips grew at a 1.3-percent annual pace. This is significantly faster than the growth in the U.S. population during this period (0.93 percent), suggesting that transit has been able to attract riders who previously used other modes of travel. Increased availability of transit service has undoubtedly been a factor in this success.

Future Capital Investment Scenarios – Systemwide

As in the highway discussion, the transit investment scenarios that follow pertain to spending by all levels of government combined for the 20-year period from 2010 to 2030 (reflecting the impacts of spending from 2011 through 2030); the funding levels associated with all of these analyses are stated in constant 2010 dollars. Unlike the highway scenarios, these transit scenarios assume an immediate jump to a higher (or lower) investment level that is maintained in constant dollar terms throughout the analysis period.

Included in this section for comparison purposes is an assessment of the investment level needed to replace all assets that are currently past their useful life or that will be over the forecast period. This would be necessary to achieve and maintain a state of good repair (SGR) but would not address any increases in demand during that period. Although not a realistic scenario, this does provide a benchmark for infrastructure preservation.

Sustain 2010 Spending Scenario

- The **Sustain 2010 Spending scenario** assumes that capital spending by all levels of government is sustained in constant dollar terms at the 2010 level ($16.5 billion systemwide), including Recovery Act funds, through 2030. Assuming that the current split between expansion and preservation investments is maintained, this will allow for enough expansion to meet medium growth expectations but will fall far short of meeting system preservation needs. By 2030, this will result in roughly $142 billion in deferred system preservation projects.

Low-Growth Scenario

- The **Low-growth scenario** assumes that transit ridership will grow at an annual rate of 1.4 percent between 2010 to 2030, as projected by the Nation's metropolitan planning organizations. During that period, it also attempts to pay down the current $85.9 billion system preservation backlog (subject to a cost-benefit constraint). The annualized cost of this scenario is $22.0 billion. In 2010, all levels of government spent a combined $16.5 billion for transit capital improvements.

High-Growth Scenario

- The **High-growth scenario** assumes that transit ridership will grow at an annual rate of 2.2 percent between 2010 and 2030, the average annual rate of growth experienced between 1995 and 2010. It also attempts to pay down the current $85.9-billion system preservation backlog (subject to the same cost-benefit constraint). The annualized cost of this scenario is $24.5 billion.

State of Good Repair – Expansion vs. Preservation

State of Good Repair (SGR) is defined in this report as all transit capital assets being within their average service life. This is a general construct that allows FTA to estimate *system preservation* needs. The analysis looks at the age of all transit assets and adds the value of those that are past the age at which that type of asset is usually replaced to a total reinvestment needs estimate. Some assets may continue to provide reliable service well past the average replacement age and others will not; over the large number of assets nationally, the differences average out. Some assets will need to be replaced, some will just get refurbished. Both types of cost are included in the reinvestment total. SGR is a measure of system preservation needs, and failure to meet these needs results in increased operating costs and poor service.

Expansion needs are treated separately in this analysis. They result from the need to add vehicles and route miles to accommodate more riders. Estimates of future demand are, by their nature, speculative. Failure to meet this type of need results in crowded vehicles and represents a lost opportunity to provide the benefits of transit to a wider customer base.

PART I

Description of Current System

Part I of this report summarizes the current state of highways, bridges and transit systems, based primarily on data through the year 2010 unless otherwise noted. Chapter 1 discusses trends in personal travel, drawing upon the 2009 National Household Travel Survey, and presents data and issues relating to highway freight movement. Chapter 2 describes the characteristics of the highway, bridge, and transit systems, and Chapter 6 provides data on the revenue collected and expended for highways and transit.

U.S. Department of Transportation (DOT) Strategic Plan, FY 2012–16

The latest U.S. DOT Strategic Plan presents five strategic goals for America's transportation system:

- **Safety** – Improve public health and safety by reducing transportation-related fatalities and injuries.
- **State of Good Repair** – Ensure that the United States proactively maintains its critical transportation infrastructure in a state of good repair.
- **Economic Competitiveness** – Promote transportation policies and investments that bring lasting and equitable economic benefits to the Nation and its citizens.
- **Livable Communities** – Foster livable communities through place-based policies and investments that increase the transportation choices and access to transportation services.
- **Environmental Sustainability** – Advance environmentally sustainable policies and investments that reduce carbon and other harmful emissions from transportation sources.

Chapter 3 addresses issues relating to the State of Good Repair goal, presenting data on the physical conditions of highways, bridges, transit systems, and transit vehicles. Chapter 4 addresses issues pertaining to the Safety goal. Chapter 5 covers topics relating to the goals for Livable Communities, Environmental Sustainability, and Economic Competitiveness.

Performance Management

Transportation Performance Management is a strategic approach that uses system information to make investment and policy decisions to achieve national performance goals. A typical performance management process would include the following elements: (1) establish a set of goals/objectives; (2) define measures that support achievement of the goal or objective; (3) establish specific future targets for the measures; (4) develop specific plans, budgets, and programs to achieve the target outcome; and (5) after the programs are implemented, assess their results against the desired target. Any discrepancy between the planned and actual outcomes can be addressed by altering strategies. Performance management is a continual improvement process.

In July 2012, the Moving Ahead for Progress into the 21st Century Act (MAP-21) introduced specific requirements for performance management for highway and transit investments, establishing national goals for safety, infrastructure condition, congestion reduction, system reliability, freight movement and economic activity, environmental sustainability, and reduced project delivery time.

Federal Agencies are required to define the measures and standards for achieving the goals identified, unless defined in MAP-21. The States are to determine their own targets, while minimum standards may be established by Federal agencies where appropriate. States are to report progress toward the targets established. Failure to meet targets or develop plans has specific penalties for States: reduction in funding or requirements to spend more on the specific goal area. States are to report progress toward the targets within 4 years of enactment of MAP-21, and biennially thereafter.

Transit agencies that receive FTA grant funds are similarly required to maintain asset management plans, to set goals for achieving a state of good repair, and to report asset inventory condition data to FTA along with metrics demonstrating their progress toward meeting their goals.

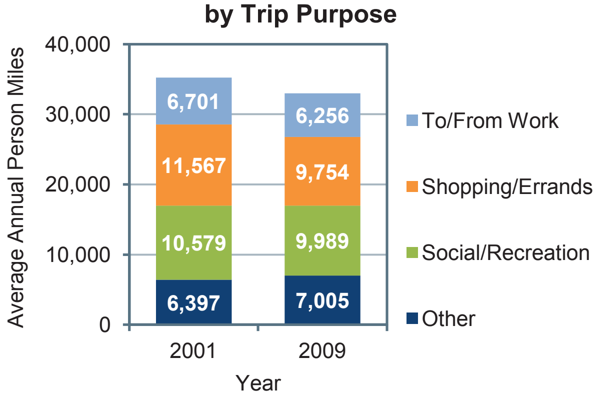
CHAPTER 1

Household Travel

To fully understand daily travel, one must look at it through the lens of the 300 million Americans who use the transportation system to connect to jobs, stores, schools, friends, relatives, healthcare, recreational places, and more. The National Household Travel Survey (NHTS) is the only national source of travel data that connects daily travel behavior with the characteristics of the household and the individual making the trip.

The NHTS data reflect daily travel behavior of the American public, and do not include freight movement or commercial driving. Americans drove 30 billion fewer vehicle miles in 2008-2009 than in the 2001-2002 NHTS survey period despite a nearly 10 percent population increase over that time. There are many factors that could be causing this decline, including: the recession, high gas prices during the summer of 2008, changing demographics (e.g., the aging of the population and smaller household sizes) changing lifestyles of Americans (e.g., the increases in telecommuting and cyber shopping or different travel preferences), an increase in the availability of quality transit service and other alternatives to driving, or roadway congestion. The NHTS results also show that transit ridership increased by 16 percent between the two survey periods; most of the increase was in the shopping and social/ recreational activities categories. For all modes of travel combined, average daily person miles of travel per household dropped from 96.6 to 90.4.

Average Annual Person Miles per Household by Trip Purpose



By 2050, about one in four members of the U.S. population will be over the age of 65. Maintaining the mobility of this group is a major quality of life issue. This group is increasing in average age over time, which may explain the recent decreases in their per capita trips and miles traveled.

Like the population as a whole, the household vehicle fleet is also aging, with the average age of household vehicles now reaching an all-time high of 9.4 years. Because more than half of the household vehicles are now older than 9 years, recent automotive advances in energy efficiency, air quality, and safety are not fully represented in the vehicles on the road.

Age of Household Vehicles

Model Years	Percent of Total
≤1 Year	5.7%
2-5 Years	28.6%
6-10 Years	32.2%
11-20 Years	26.9%
>20 Years	6.7%

Much attention has been given to changes in the travel behavior of the Millennial generation, generally defined as those born between 1982 and 2000. The NHTS results indicate that youth travel is declining as they are driving less, traveling less, and taking shorter trips compared with previous generations. Recent research has identified several contributing factors to this trend, including:

- Technology influences travel and how youth get their information.
- Youth concerns for the environment play a role in their travel decisions.
- More youth prefer to live in high-density areas where there are more modal options and shorter trip lengths.
- High unemployment and personal income constraints limit resources for travel and cause youth to live with parents longer.
- Increases in driver's licensing restrictions have resulted in more youth waiting longer to get their license.

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CHAPTER 1

Freight Movement

The freight transportation system plays a major role in promoting and sustaining the economic vitality of the United States. Various businesses, ranging from companies that mine raw materials that are used to manufacture goods to retail companies selling household goods or office products, rely on the U.S. freight transportation system to have their products picked-up and/or delivered.

Though the system includes a variety of transportation modes (highway, railroad, waterway, aviation, and pipeline), some of which are publicly owned and others of which are privately owned, most of the system has a high degree of connectivity. This allows freight carriers to operate more efficiently and shippers to use the most economically effective mode or modes for shipping their goods.

The well-developed transportation system currently handles over 50 million tons of freight each day, with over two-thirds of that amount being carried by trucks. This high volume of freight movement, which has grown steadily over the last few decades due to the ease of transport in the United States and an increase in interregional domestic and international trade, is putting increasing stress on the transportation system. Freight volumes are expected to continue to increase across all modes in the coming years, challenging the transportation system even more.

Based on projections from the FHWA Freight Analysis Framework, combined tonnage for all freight modes is projected to increase by 1.4 percent per year over the next 30 years to 27.4 billion in 2040. The weight of shipments carried by trucks is projected to increase by 1.3 percent per year during this period, rising from 12.5 billion tons to 18.5 billion tons.

Though trucking typically is considered a faster mode and handles a large volume (87 percent) of high-value, time-sensitive goods, it also hands a surprising share (71 percent) of lower-value bulk tonnage. This share includes movement of agricultural products from farms, local distribution of gasoline, and pickup of municipal solid waste.

Weight of Shipments by Transportation Mode (Millions of Tons)

Mode	2010	2040 Projected	Average Annual Growth, 2010–2040
Truck	12,490	18,503	1.3%
Rail	1,776	2,353	0.9%
Water	860	1,263	1.3%
Air, Air & Truck*	12	43	4.4%
Multiple Modes & Mail	1,380	2,991	2.6%
Pipeline	1,494	1,818	0.7%
Other & Unknown	302	514	1.8%
Total	**18,313**	**27,484**	**1.4%**

*Includes air cargo movements that are shipped via truck at the ends of the trips.

The growth in freight shipments will make it more difficult for freight carriers to continue to operate efficiently, particularly if capacity expansions and/or operational improvements are not implemented on major freight corridors and at major freight nodes. In turn, decreased operational efficiency would increase transportation costs, negatively impacting carriers, shippers, and ultimately consumers.

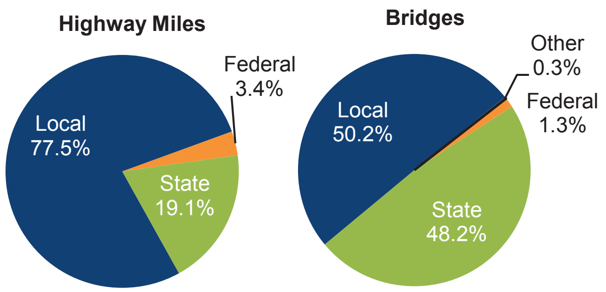
The increased focus on freight transportation needs in the Moving Ahead for Progress in the 21st Century (MAP-21) surface transportation reauthorization legislation should help address the growing freight needs in the United States. By designating a national freight network, requiring the formulation of a national freight strategic plan, and refining transportation investment and planning tools to evaluate freight projects, among other requirements, freight transportation needs should become more easily identifiable, and transportation funding decisions should become more strategic in nature. These legislative changes will likely help enhance the U.S. freight transportation system in the long term.

CHAPTER 2

System Characteristics: Highways and Bridges

Spanning more than 4.08 million miles and including 604,493 bridges, the Nation's public road network facilitated slightly less than three trillion VMT in 2010. Local governments owned 77.5 percent of the Nation's public road mileage and 50.2 percent of the Nation's bridges in 2010; States owned 19.1 percent of mileage and 48.2 percent of bridges; the Federal government owned 3.4 percent of mileage and 1.3 percent of bridges.

2010 Mileage and Bridges by Owner



As of 2010, the National Highway System (NHS) included 162,876 miles of the Nation's key corridors (4.0 percent of total mileage) which carried 43.0 percent of VMT. The revised NHS criteria in MAP-21 will add to the NHS most of the principal arterial mileage that is not currently part of the system. If all principal arterial mileage were added, this would cover 5.5 percent of the Nation's route miles and 55.2 percent of VMT. (This estimate of the extent of the enhanced NHS is used in Chapters 7 and 8 in developing 20-year NHS investment/ performance projections.)

MAP-21 requires the creation and definition of a new National Freight Network, which is intended to include the most important urban, rural, and intercity routes for commercial truck movements. This network will include a Primary Freight Network of up to 27,000 miles to be designated by the U.S. DOT, other Interstate highways not included in the Primary Freight Network, and Critical Rural Freight Corridors to be designated by the States.

Rural mileage (in areas with population less than 5,000) decreased an at an average annual rate of 0.4 percent between 2000 and 2010, in part due to the expansion of urban area boundaries following the 2000 Census. Urban mileage increased at a rate of 2.5 percent annually during this period.

Roads are functionally classified based on the purpose they serve in terms of providing mobility and access. Almost half of the Nation's road mileage is classified as rural local, but these roads carry only 4.5 percent of VMT.

2010 Percentage of Highway Miles, Bridges, and Vehicle Miles Traveled by Functional System

Functional System	Miles	VMT	Bridges
Rural Areas			
Interstate	0.7%	8.2%	4.2%
Other Freeway and Expressway	0.1%	0.6%	
Other Principal Arterial	2.2%	6.8%	6.0%
Minor Arterial	3.3%	5.1%	6.5%
Major Collector	10.2%	6.0%	15.4%
Minor Collector	6.4%	1.8%	7.9%
Local	49.7%	4.5%	34.0%
Subtotal Rural	**72.7%**	**32.9%**	**73.9%**
Urban Areas			
Interstate	0.4%	16.0%	5.0%
Other Freeway and Expressway	0.3%	6.7%	3.3%
Other Principal Arterial	1.6%	15.5%	4.5%
Minor Arterial	2.6%	13.0%	4.6%
Major Collector	2.8%	6.1%	3.4%
Minor Collector	0.0%	0.1%	
Local	19.6%	9.7%	5.3%
Subtotal Urban	**27.3%**	**67.1%**	**26.1%**
Total	**100.0%**	**100.0%**	**100.0%**

Bridges on rural other freeway and expressway included under rural other principal arterial. Bridges on urban minor collector included under urban major collector.

The term "Federal-aid Highways" refers to the subset of the road network that is generally eligible for Federal funding assistance under most programs; this excludes roads functionally classified as rural minor collector, rural local or urban local. Federal-aid highways make up 24.7 percent of the nation's mileage, but carry 84.6 percent of VMT.

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CHAPTER 2

System Characteristics: Transit

Between 2000 and 2010, transit system coverage, capacity, and use in the United States all experienced steady growth. In 2010, there were 728 agencies (709 public agencies) in urbanized areas required to submit data to the National Transit Database (NTD). All but 148 of these agencies operated more than one mode. There were also 1,582 rural transit operators that reported. Urban reporters operated 612 motor bus systems, 587 demand response systems, 18 heavy rail systems, 30 commuter rail systems, and 33 light rail systems. There were also 70 transit vanpool systems, 20 ferryboat systems, 5 trolleybus systems, 3 automated guideway systems, 3 inclined plane systems, and 1 cable car system.

U.S. transit systems operated 74,319 motor buses, 33,458 vans, 11,434 heavy rail vehicles, 7,072 commuter rail cars, and 2,118 light rail cars. Transit providers operated 12,438 miles of track and served 3,175 stations. Almost all transit providers are included in these counts, excepting those that do not receive FTA grant funds and choose not to report to NTD.

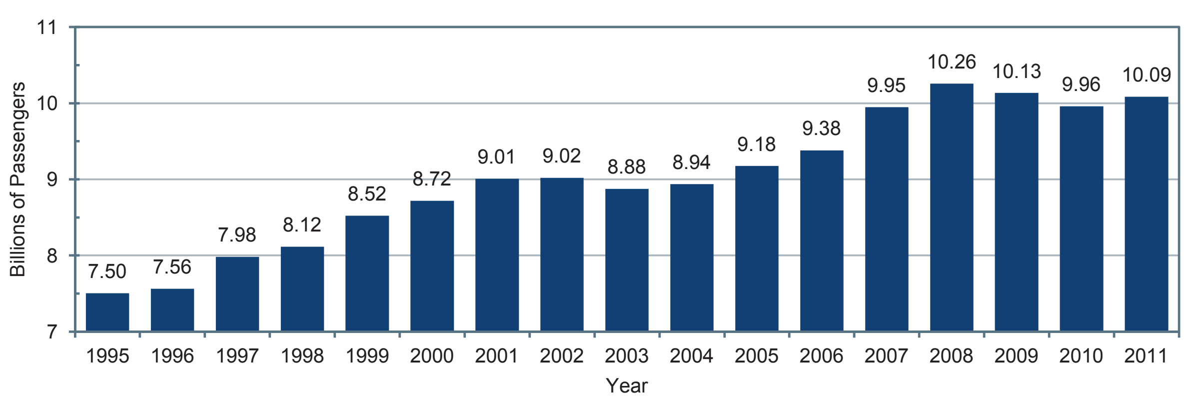
Motor bus and heavy rail modes continue to be the largest segments of the industry, providing 51.6 percent and 35.6 percent of all transit trips, respectively. Commuter rail, with 4.6 percent of trips, supports a relatively high share of passenger miles (20.0 percent) due to its greater average trip length (23.4 miles compared with 4.0 for bus, 4.6 for heavy rail, and 4.8 for light rail). Light rail is the fastest-growing rail mode (with passenger miles traveled [PMT] growing at 5.0 percent per year between 2000 and 2010) but still provided only 4.1 percent of transit PMT in 2010. Vanpool growth during that period was 10.3 percent per year, substantially outpacing the 0.9-percent growth in motor bus passenger miles; however, while motor buses provided 39.1 percent of all PMT, vanpools accounted for only 2.1 percent.

Transit systems are concentrated in the 42 urbanized areas with populations of more than 1 million people. These areas contain about half of the U.S. population, but their higher population densities and long-term investments in transit infrastructure support 89 percent of all transit trips on 77 percent of the vehicle revenue miles.

Rural transit operators reported 123.2 million unlinked passenger trips on 570 million vehicle revenue miles. This included 61 Indian tribes that provided 1,008,701 unlinked passenger trips. Rural systems provide both traditional fixed-route and demand response services. In 2010, there were 1,180 demand response systems, including 30 systems added since 2008, and 530 motor bus systems, including 36 added since 2008. Sixteen rural systems reported vanpool operations.

Rural service is provided in every State, and 327 urbanized area agencies reported providing service to rural areas as well.

Annual U.S. Unlinked Transit Passenger Trips, 1995–2011



CHAPTER 3

System Conditions: Highways

Highway users are economically impacted by the conditions of the highways and bridges they utilize. Users are more likely to incur higher vehicle maintenance costs for travel on roads with poor pavement conditions, particularly on higher speed roads like Interstate highways. Poor pavement conditions may also increase travel time due to drivers slowing down and avoiding risks like potholes, which can also escalate the level of congestion on the Nation's most traveled roadways.

Urban centers facilitate more than two-thirds of VMT on the Nation's highway system. Pavement conditions in urban settings tend to deteriorate at a faster rate because of the higher usage. Replacing pavement in urban centers is also challenging because roadwork can exacerbate congestion.

The Highway Performance Monitoring System (HPMS) includes data on pavement ride quality on Federal-aid highways, which includes about one-quarter of the Nation's mileage. Between 2000 and 2010, the percentage of rural VMT on pavements classified as having acceptable ride quality declined from 93.8 percent to 87.8 percent. However, the percent of rural VMT on pavements with good ride quality (a subset of the acceptable ride quality classification) increased from 55.2 percent to 64.6 percent. The share of urban VMT on pavements with good ride quality rose from 35.0 percent in 2000 to 44.0 percent in 2010, while the share on pavements with acceptable ride quality declined from 80.3 percent to 79.4 percent.

Percent of Federal-aid Highway VMT on Pavements With Good and Acceptable Ride Quality

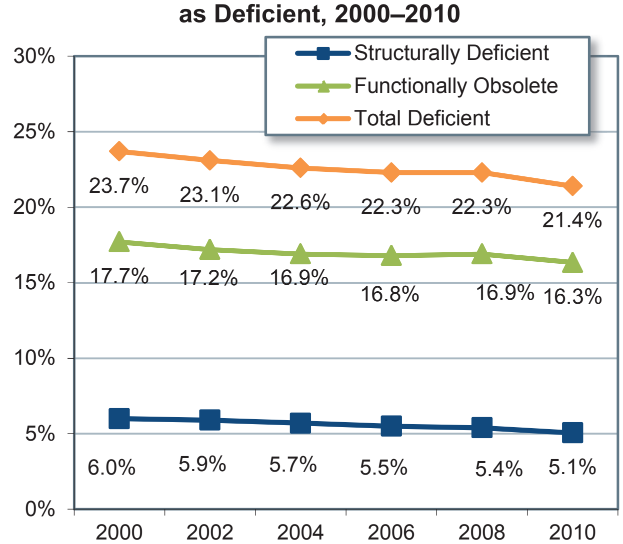
Ride Quality	Calendar Year 2000	2008	2010
Good (IRI < 95)			
Rural	55.2%	62.5%	64.6%
Urban	35.0%	38.9%	44.0%
Total	42.8%	46.4%	50.6%
Acceptable (IRI ≤ 170)			
Rural	93.8%	94.8%	87.8%
Urban	80.3%	81.0%	79.4%
Total	85.5%	85.4%	82.0%

The share of National Highway System (NHS) VMT on pavements with good ride quality rose from 48 percent in 2000 to 60 percent in 2010.

Bridges are another vital component for the Nation's highway system. Two terms used to summarize bridge deficiencies are "structurally deficient" and "functionally obsolete." Structural deficiencies are characterized by deteriorated conditions of significant bridge elements and potentially reduced load-carrying capacity, but do not necessarily imply safety concerns. Functional obsolescence is characterized by bridges not meeting current design standards, such as lane width or number of lanes, relative to the traffic volume carried by the bridge.

The percentage of NHS bridges classified as deficient decreased from 23.7 percent in 2000 to 21.4 percent in 2010. Of the 116,669 bridges on the NHS in 2010, 5.1 percent of bridges were classified as structurally deficient while 16.3 percent of bridges were classified as functionally obsolete.

Percentage of NHS Bridges Classified as Deficient, 2000–2010



Almost 68.5 percent of the Nation's 604,493 bridges were 26 years old or older as of 2010, up from 67.2 percent in 2000. The share of total bridges classified as structurally deficient as of 2010 was 11.5 percent, and 12.8 percent of bridges were functionally obsolete.

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CHAPTER 3

System Conditions: Transit

This edition of the C&P report discusses levels of investment needed to achieve a "state of good repair" benchmark. The FTA uses a numerical condition rating scale ranging from 1 to 5 (detailed in Chapter 3) to describe the relative condition of transit assets as estimated by the Transit Economic Requirements Model (TERM). Assets are considered to be in a state of good repair when the physical condition of that asset is at or above a condition rating value of 2.5 (the mid-point of the marginal range). An entire transit system is considered to be in a state of good repair when all of its assets are rated at or above the 2.5 threshold rating. This report estimates the cost of replacing all assets in the national inventory that are past their useful life (that is, below the 2.5 condition rating) to be a total of $85.9 billion. This is 13 percent of the estimated total asset value of $678.9 billion for the entire U.S. transit industry.

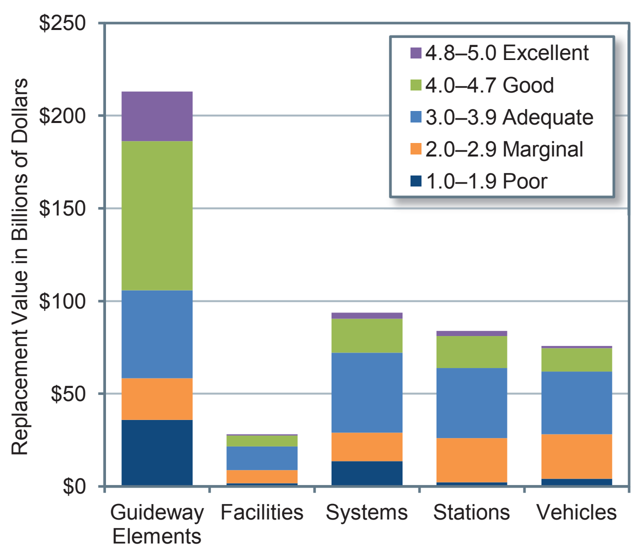
The cost-weighted average condition rating over all bus types is at the bottom of the adequate range (3.0), slightly lower than it has been for the past decade. The full-size bus fleet shows decreases in average age and percentage of vehicles that are below the state of good repair replacement threshold. The average age of the bus fleet is now 6.1 years.

A reduction of 1.2 percent in the number of full-sized buses may indicate that older vehicles are being removed from the fleet. If so, this represents a welcome reversal of trends seen in the 2010 edition of this report. The total number of vehicles reported is up 14 percent over the last 4 years. This is driven by a 46-percent increase in the number of vans and a 42-percent increase in the number of articulated buses (extra-long buses with two connected passenger compartments) during this 4-year period.

The cost-weighted average condition rating for all rail vehicles is near the middle of the adequate range (3.5), where it has been without appreciable change for the past decade. With average conditions and ages being quite stable over the last 5 years, the most significant aspect of the rail vehicle data presented here is the steady growth in the size of the fleet, which increased at an average annual rate of 2.1 percent between 2000 and 2010. By comparison, the U.S. population increased at an average annual rate of only 0.93 percent.

Non-vehicle transit rail assets represent the biggest challenge to achieving a state of good repair. The estimated replacement value of guideway elements (track, ties, switches, ballast, tunnels, and elevated structures) is $213.0 billion, of which $35.8 billion is for assets in poor condition (17 percent) and $22.6 billion is for assets in marginal condition. The replacement value of train systems (power, communication, and train control equipment) is estimated at $93.6 billion, of which $13.7 billion is for systems in poor condition (15 percent) and $15.3 billion is for systems in marginal condition. The relatively large proportion of guideway and systems assets that are in poor condition, and the magnitude of the $49.5-billion investment required to replace them, represents a major challenge to the rail transit industry.

Distribution of Asset Physical Conditions by Asset Type for All Rail



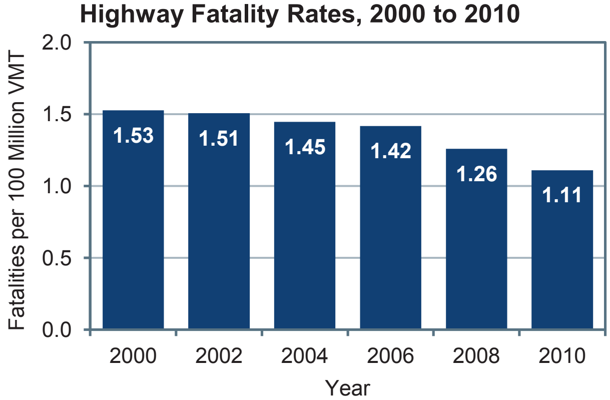
CHAPTER 4

Safety: Highways

There has been considerable improvement in highway safety since Federal legislation first addressed the issue in 1966; in that year alone, 50,894 Americans lost their lives in crashes. Traffic deaths reached their highest point in 1972 with 54,589 fatalities, then declined sharply following the implementation of a national speed limit, reaching a low of 39,250 fatalities in 1992. Between 1992 and 2006, there was more limited progress in reducing the number of fatalities, and by 2006 the annual number of fatalities had risen to 42,708. The annual number of traffic deaths has subsequently declined; there were 32,885 fatalities in 2010, a record low in the post-1966 era.

The fatality rate per VMT provides a metric that allows transportation professionals to consider fatalities in terms of the additional exposure associated with driving more miles. In 1966, the fatality rate was 5.50 fatalities per 100 million VMT. By 2010, the fatality rate had declined to 1.11 per 100 million VMT. It is also worth noting that the number of fatalities decreased by 23 percent between 2006 and 2010, coinciding with the timing of the implementation of FHWA's Highway Safety Improvement Program (HSIP).

Highway Fatality Rates, 2000 to 2010



At the same time that the overall number of fatalities dropped by more than 26 percent in 20 years (between 1990 and 2010), the overall number of traffic-related injuries also decreased by almost 35 percent (from 3.2 million to 2.1 million). Injuries increased between 1992 and 1996, but have steadily declined since then. In 1990, the injury rate was 151 per 100 million VMT; by 2010, the number had dropped by almost 53 percent to 71 per 100 million VMT.

FHWA has three focus areas related to the reduction of crashes: roadway departures, intersections, and pedestrian crashes. These three focus areas have been selected because they account for a noteworthy portion of overall fatalities and represent an opportunity to significantly impact the overall number of fatalities and serious injuries. In 2010, roadway departure, intersection, and pedestrian fatalities accounted for 52.9 percent, 20.3 percent, and 13.0 percent, respectively, of all crash fatalities.

Highway Fatalities by Crash Type, 2000 to 2010

	2000	2010	Percent Change
Roadway Departures	23,046	17,389	-24.5%
Intersection-Related	8,689	6,758	-22.2%
Pedestrian-Related	4,763	4,280	-10.1%

In 2010, there were 17,389 roadway departure fatalities. In some cases, the vehicle crossed the centerline and struck another vehicle, hitting it head-on or sideswiping it. In other cases, the vehicle left the roadway and struck one or more manmade or natural objects, such as utility poles, embankments, guardrails, trees, or parked vehicles.

Of the 32,885 fatalities that occurred in 2010, 6,673 occurred at intersections. Rural intersections accounted for 38.3 percent of intersection fatalities and urban accounted for 61.7 percent.

The number of pedestrian fatalities decreased 10.1 percent, from 4,763 in 2000 to 4,280 in 2010. Total nonmotorist fatalities (including pedestrians, bicyclists, etc.) decreased from 5,597 in 2000 to an 11-year low of 4,888 in 2009 before rising to 5,080 in 2010.

CHAPTER 4

Safety: Transit

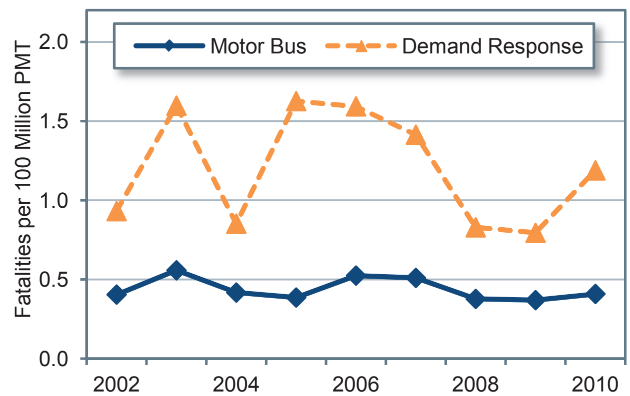
Based on the number of fatalities and injuries reported on an annual basis, public transportation generally experiences lower rates of incident, fatality, and injury than other modes of transportation in the same year. However, serious incidents do occur, and the potential for catastrophic events remains. Several transit agencies in recent years have had major accidents that resulted in fatalities, injuries, and significant property damage. The National Transportation Safety Board (NTSB) has investigated a number of these accidents and has issued reports identifying their probable causes and the factors that contributed to them. Since 2004, the NTSB has reported on nine transit accidents that, collectively, resulted in 15 fatalities, 297 injuries, and over $30 million in property damage.

Since 2002, there has been no significant decrease in the rate of transit fatalities, excluding suicides. From 2002 to 2010, the number of fatalities has remained relatively flat while the rate per 100 million passenger miles has declined slightly due to increasing ridership. Unlike other modes, such as highway travel, public transportation has not achieved a consistent decrease in fatalities.

Transit interaction with pedestrians, cyclists, and motorists at rail grade crossings, pedestrian crosswalks, and intersections largely drives overall transit safety performance. The majority of fatalities and injuries in public transportation result from interaction with the public on busy city streets, from suicides, and from trespassing on transit right-of-way and facilities. Pedestrian fatalities accounted for 29 percent of all transit fatalities in 2010.

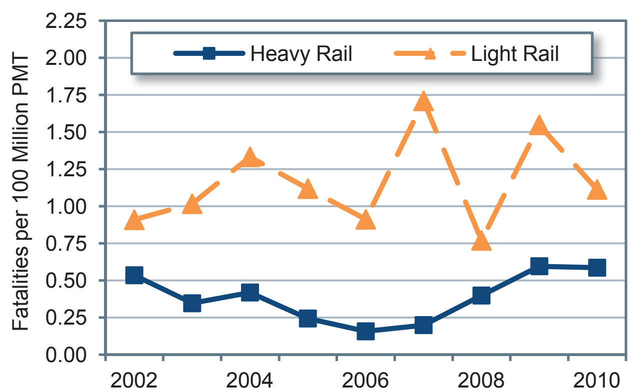
Although public fatalities have been decreasing in recent years, suicides have steadily increased. This change could be attributed to improvements arising from clarifications to the procedures for reporting and distinguishing between trespasser fatalities and suicides, or it could indicate a rising trend of suicides in public transportation environments. On average, fatalities involving suicides and persons who are not transit passengers or patrons (usually pedestrians and drivers) account for about 75 percent of all public transportation fatalities.

Annual Transit Fatality Rates by Highway Mode, 2002–2010



Note: Fatality totals include both Directly Operated (DO) and Purchased Transportation (PT) service types.

Annual Transit Fatality Rates by Rail Mode, 2002–2010



Note: Fatality totals include both Directly Operated (DO) and Purchased Transportation (PT) service types.

CHAPTER 5

System Performance: Highways

This chapter relates to three of the goals in the U.S. DOT Strategic Plan FY 2012–FY2016: (1) to "Foster livable communities through place-based policies and investments that increase transportation choices and access to transportation services;" (2) to "Advance environmentally sustainable policies and investments that reduce carbon and other harmful emissions from transportation sources;" and (3) to "Promote transportation policies and investments that bring lasting and equitable economic benefits to the Nation and its citizens."

Sustainable Transportation Systems

Transportation systems that balance the access and mobility needs of all users—motorists, truckers, emergency vehicles, bicyclists, pedestrians, and transit riders—are an important aspect of livable communities. Incorporating community input and other livability considerations into transportation, land use, and housing policies can help improve public health and safety, lower infrastructure costs, reduce combined household transportation and housing costs, reduce vehicle miles traveled, and improve air and water quality, among many other benefits.

Sustainability emphasizes the natural environment, the economic efficiency of the transportation system, and societal needs (e.g., mobility, accessibility, and safety). Transportation agencies currently address sustainability through a wide range of initiatives, such as Intelligent Transportation Systems, linking transportation and land use decision-making, linking planning and environment, and addressing requirements of the National Environmental Policy Act. From an environmental sustainability perspective, FHWA helps ensure that regions continue to make progress towards their air-quality standards through the Congestion Mitigation and Air Quality Improvement (CMAQ) Program, promoting strategies to reduce greenhouse gas emissions, and assisting transportation agencies in adapting to the impacts of climate change and extreme weather events.

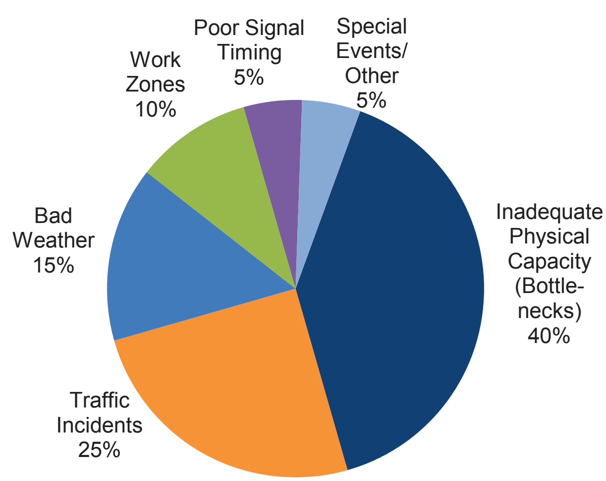
Economic Competitiveness

Maintaining economic competitiveness means increasing and maximizing the contribution of the transportation system to economic growth.

Heavy congestion has an adverse impact on the American economy. The problem is of particular concern to firms involved in logistics and distribution. As just-in-time delivery increases, firms need an integrated transportation network that allows for the reliable, predictable shipment of goods. If travel time were to increase or reliability were to decrease, businesses would need to increase average inventory levels to compensate, which increases storage costs and adds to the final costs of goods.

Congestion results when traffic demand approaches or exceeds the available capacity of the system. Recurring congestion occurs in roughly the same place and time on the same days of the week if the physical infrastructure is not adequate to accommodate demand during peak periods. Nonrecurring congestion is caused by temporary disruptions that take away part of the roadway from use. The three main causes of nonrecurring congestion are: incidents ranging from a flat tire to an overturned hazardous material truck, work zones, and weather.

Sources of Congestion



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CHAPTER 5

System Performance: Transit

The transit industry has been successful at meeting the growing demand for its services in communities across the country. While many transit agencies experienced budget reductions during the last decade, analyses of transit data from the end of the last decade show steady increases in service provided. This is accompanied by improvements in a number of efficiency indicators and in ridership.

Between 2000 and 2010, transit route miles of service and vehicle revenue miles on those routes have steadily increased for all the major transit modes. This has been done without significant decreases in vehicle occupancy. In addition, the mean distance transit vehicles operated between mechanical breakdowns has decreased (by 14 percent).

Between 2000 and 2010, transit agencies provided substantially more service. The overall annual rate of growth in urban directional route miles was 1.9 percent with a range from 0.4 percent for heavy rail to 6.0 percent for light rail, and bus route miles grew at 1.9 percent per year. This has resulted in 21 percent more route miles available to the public with growth focused on the light rail and commuter rail systems that are most likely to attract riders from automobiles.

Growth in route miles was matched by 2.0-percent annual overall growth in vehicle revenue miles. This indicates that the new route miles are being served at a frequency similar to that of the previous routes. This demonstrates a true expansion of service to more neighborhoods and more people. Vehicle revenue mile growth for vanpools was particularly large, but recent increases in reporting account for much of this increase.

Growth in service offered was almost matched by growth in ridership. In spite of steady growth in route miles and revenue miles, average vehicle occupancy levels remained stable. Passenger miles traveled grew at a 1.6-percent annual pace while the number of unlinked passenger trips grew at a 1.3 percent annual pace. This is significantly faster than the growth in the U.S. population during this period (0.93 percent), possibly suggesting that transit has been able to attract riders who previously used other modes of travel. Increased availability of transit service has undoubtedly been a factor in this success.

The two fastest-growing rail modes—light rail and commuter rail—did have some trouble maintaining occupancy levels; their per-vehicle occupancies are down 9.2 percent and 9.8 percent, respectively, since 2000. The other major modes are largely unchanged. Several urbanized areas, including Denver, Phoenix, Seattle, Charlotte, and Salt Lake City, recently opened new light rail systems and it typically takes several years for a new system to realize its full ridership potential.

Productivity per active vehicle increased between 2000 and 2010. Vehicle in-service mileage increased steadily from 2000 to 2008 before leveling off between 2008 and 2010. For the decade, all the major modes showed increases in vehicle use. Light rail and demand response have shown a particularly strong improvement in vehicle miles per active vehicle.

Rail and Nonrail Vehicle Revenue Miles, 2000–2010

	Miles (Millions)						Average Annual Rate of Change
Transit Mode	2000	2002	2004	2006	2008	2010	2010/2000
Rail	**879**	**925**	**963**	**997**	**1,054**	**1,056**	**1.9%**
Heavy Rail	578	603	625	634	655	647	1.1%
Commuter Rail	248	259	269	287	309	315	2.4%
Light Rail	51	60	67	73	86	92	6.0%
Other Rail	2	3	2	3	3	2	1.7%
Nonrail	**2,322**	**2,502**	**2,586**	**2,674**	**2,841**	**2,863**	**2.1%**
Motor Bus	1,764	1,864	1,885	1,910	1,956	1,917	0.8%
Demand Response	452	525	561	607	688	718	4.7%
Vanpool	62	71	78	110	157	181	11.3%
Ferryboat	2	3	3	3	3	3	5.0%
Trolleybus	14	13	13	12	11	12	-1.8%
Other Nonrail	28	26	46	32	25	32	1.5%
Total	**3,201**	**3,427**	**3,549**	**3,671**	**3,895**	**3,920**	**2.0%**

CHAPTER 6

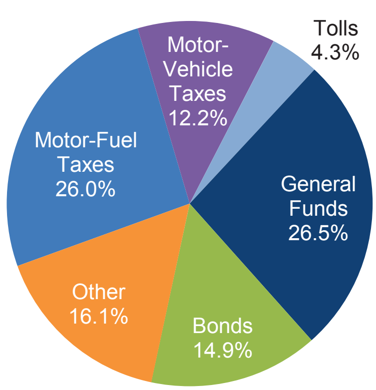
Finance: Highways

Highway revenue totaling $221.0 billion was collected by all levels of government in 2010, while $205.3 billion was spent on highways during the year. (The net difference of $15.7 billion was added into reserves for use in future years.)

User charges such as motor-fuel and motor-vehicle tax receipts and tolls have traditionally provided the majority of the combined revenues raised for highway and bridge programs by all levels of government. However, at the Federal level, the total proceeds to the Highway Trust Fund (HTF) from dedicated excise taxes have fallen below annual expenditures for several years. As recently as 2007, the share of Federal highway revenue derived from user charges was 92.8 percent, but this share has subsequently dropped to 48.8 percent in 2010. This decline is the result of a legislated $14.7 billion transfer of general funds to the HTF, as well as the expenditure in 2010 of **$11.9 billion of funding authorized by the Recovery Act**.

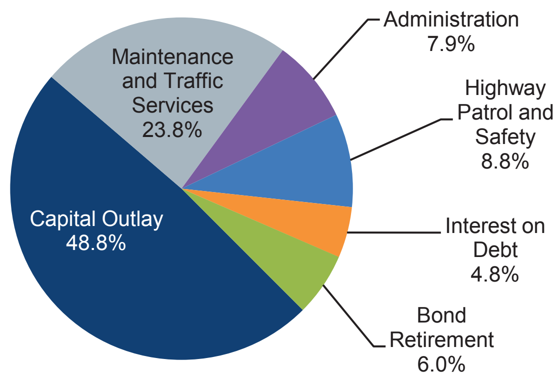
In 2010, $93.8 billion (42.5 percent, down from 62.0 percent in 2000) of the revenue generated for spending on highways and bridges by all levels of government came from highway-user charges. General fund appropriations totaled $58.6 billion (26.5 percent) and bond proceeds totaled $33.0 billion (14.9 percent). All other sources such as property taxes, other taxes and fees, lottery proceeds, interest income, and miscellaneous receipts totaled $35.5 billion (16.1 percent).

Revenue Sources for Highways, 2010



Of the $205.3 billion spent on highways in 2010, $100.2 billion (48.8 percent) was used for capital investment. Spending on routine maintenance and traffic services totaled $48.8 billion (23.8 percent), administrative costs (including planning and research) were $16.2 billion, $18.1 billion was spent on highway patrol and safety programs, $9.8 billion was used to pay interest, and $12.3 billion was used for bond retirement.

Highway Expenditure by Type, 2010



The portion of total capital spending directed toward system rehabilitation (resurfacing or replacing existing pavements and rehabilitating or replacing existing bridges) rose from $46.2 billion (51.1 percent of the total) in 2008 to $60.0 billion (59.9 percent of the total) in 2010, an increase of almost 30 percent over the 2 years which was partly driven by additional funding provided by the Recovery Act.

Federal cash expenditures for capital purposes grew at an average annual rate of 5.4 percent from $26.1 billion in 2000 to $44.4 billion in 2010; combined State and local capital spending grew by 4.7 percent per year during this period. Consequently, the Federally funded share of total capital outlay rose during this period (from 42.6 percent to 44.3 percent).

In inflation-adjusted, constant-dollar terms, highway capital spending increased at an average annual rate of 3.2 percent from 2000 to 2010, while total highway expenditures grew 3.1 percent per year.

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CHAPTER 6

Finance: Transit

In 2010, $54.3 billion was generated from all sources to finance transit investment and operations. Transit funding comes from *public funds* allocated by Federal, State, and local governments and *system-generated revenues* earned by transit agencies from the provision of transit services. Of the funds generated in 2010, 73.9 percent ($40.2 billion) came from public sources and 26.1 percent came from passenger fares ($12.1 billion) and other system-generated revenue sources ($2.0 billion). The Federal share of this was $10.4 billion (25.8 percent of total public funding and 19.1 percent of all funding). Local jurisdictions provided the bulk of transit funds: $18.0 billion in 2010, or 44.9 percent of total public funds and 33.2 percent of all funding.

In 2010, total public transit agency expenditures for capital investment were $16.6 billion. Annually authorized Federal funds, $4.4 billion, made up 26.6 percent of these capital expenditures. Federal funds from the American Recovery and Reinvestment Act provided another 14.5 percent. State funds provided an additional 14.2 percent and local funds provided the remaining 44.6 percent.

Of total 2010 transit capital expenditures, 72.0 percent ($11.9 billion) was invested in rail modes of transportation, compared with 28.0 percent ($4.6 billion) invested in nonrail modes. This investment distribution has been consistent over the last decade.

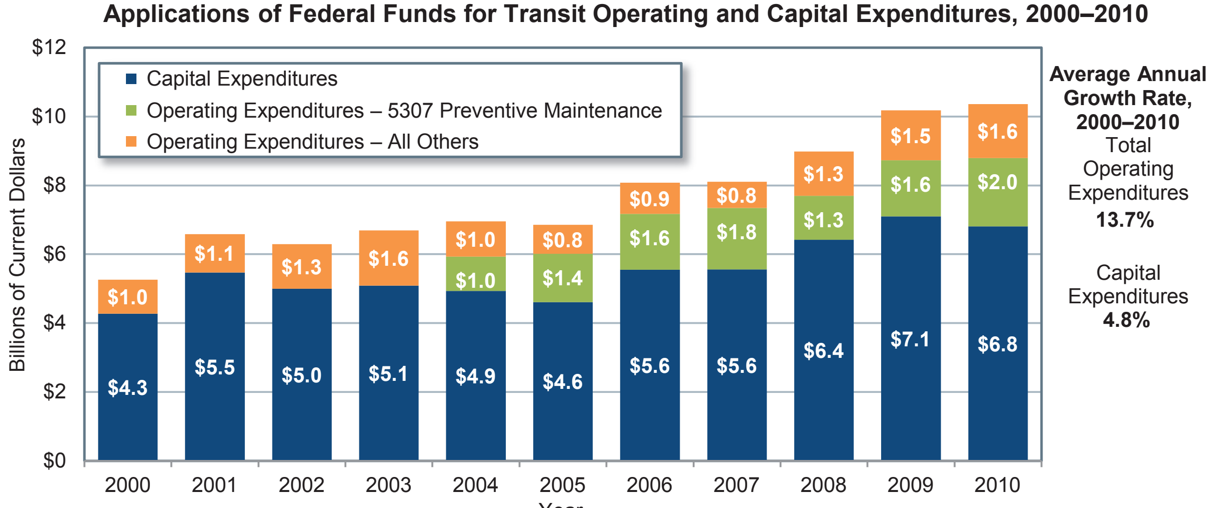
In 2010, $37.8 billion was expended on transit operating expenses (wages, salaries, fuel, spare parts, preventive maintenance, support services, and leases). The Federal share of this has increased from the 2008 level of 7.1 percent to 9.4 percent. The share generated from system revenues remained relatively stable. The State share decreased slightly from 25.8 percent in 2008 to 25.0 percent. The local share of operating expenditures (28.2 percent) has been stable for several years.

The average annual increase in operating expenditures per vehicle revenue mile for all modes combined between 2000 and 2010 was 1.3 percent. Because vehicle capacity varies across transit modes, it is customary to analyze operating costs per capacity equivalent mile. By this standard, the cost per mile to run a bus is $9.60 while the cost to run the same number of seats on a heavy rail vehicle is $3.98. Demand response (mostly provided by vans) is the most expensive to operate; a mile of bus-equivalent demand-response seats would cost $25.48.

Bus operating cost increases (2.0 percent per year) and demand response increases (3.1 percent per year) have been higher than those experienced by the rail modes (1.0 percent for heavy rail, -0.1 percent for commuter rail, and 0.4 percent for light rail).

Since 2004, some preventative maintenance costs—normally considered operating expenses—have been eligible for FTA reimbursement as capital expenses; they are shown separately in the figure below.

Applications of Federal Funds for Transit Operating and Capital Expenditures, 2000–2010



Source: National Transit Database.

PART II

Investment/Performance Analysis

The methods and assumptions used to analyze future highway, bridge, and transit investment scenarios for this report are continuously evolving to incorporate new analytical methods, new data and evidence, and changes in transportation planning objectives.

Traditional engineering-based analytical tools focus mainly on estimating transportation agency costs to maintain or improve the conditions and performance of infrastructure. This type of analytical approach can provide valuable information about the cost effectiveness of transportation system investments from the public agency perspective, including the optimal pattern of investment to minimize life-cycle costs. However, this approach does not fully consider the potential benefits to users of transportation services from maintaining or improving the conditions and performance of transportation infrastructure.

The investment/performance analyses presented in Chapters 7 through 10 were developed using the Highway Economic Requirements System (HERS), the National Bridge Investment Analysis System (NBIAS), and the Transit Economic Requirements Model (TERM). Each of these tools has a broader focus than traditional engineering-based models and takes into account the value of the services that transportation infrastructure provides to its users as well as some of the impacts that transportation activity has on non-users. Although HERS, TERM, and NBIAS all use benefit-cost analysis, their methods for implementing this analysis differ significantly. The highway, transit, and bridge models each rely on separate databases, making use of the specific data available for each mode of the transportation system and addressing issues unique to that mode. The methodologies used to analyze investment for highways, bridges, and transit are detailed in Appendices A, B, and C.

The economic approach to transportation investment relies fundamentally upon an analysis and comparison of the benefits and costs of potential investments. Projects that yield benefits whose value exceeds their costs have the potential to increase societal welfare and are thus considered "economically efficient." In practice, however, data limitations and other factors prevent any benefit-cost analysis from being fully comprehensive, and attaining national breadth of perspective for this report's analyses required that the scope be limited in other ways. The analyses do not consider, for example, environmental impacts of increased water runoff from highway pavements, barrier effects of highways for human and animal populations, the health benefits from the additional walking activity when travelers go by transit rather than by car, and some other impacts related to livability. The analyses also do not consider transportation investments packaged across modes or with demand management measures or land use policies. Future editions of the C&P report may address these issues through evidence obtained from more regionally focused modeling frameworks.

Benefits and costs are measured in this report's analysis in constant 2010 dollars to eliminate the effect of any general inflation that may be expected to occur in subsequent years. For some prices, however, the analysis projects increases at a rate different from the general rate of inflation. These include the price of motor fuels, the cost to society of carbon emissions, and, in the Chapter 10 sensitivity analysis, the value of travel time savings.

The models used in this report's analysis produce single-valued best estimates of future outcomes rather than probability distributions of outcomes. The sensitivity analysis conducted in Chapter 10 addresses the uncertainty in parameter values (discount rates, value of time saved, statistical value of lives saved, etc.). For any year, the projected outcomes are more subject to forecasting error than the differences between projected outcomes at alternative levels of investment.

Chapter 7 analyzes the projected impacts of alternative levels of future investment on measures of physical condition, operational performance, and benefits to system users. Each alternative pertains to investment from 2011 through 2030, and is

PART II

Investment/Performance Analysis

presented as an annual average level of investment and in terms of the annual rate of increase or decrease in investment that would produce that annual average. Both the level and rate of growth in investment are measured using constant 2010 dollars.

In addition to a primary set of analyses assuming State-provided VMT forecasts for highways and Metropolitan Planning Organization (MPO)-provided passenger miles traveled (PMT) forecasts for transit, Chapter 7 also includes a secondary set of analyses assuming a continuation of 15-year growth trends. For highways, this alternative travel growth rate is lower than the State forecasts; for transit, the alternative growth rate is higher than the MPO forecasts.

Chapter 8 examines several scenarios distilled from the investment alternatives considered in Chapter 7. Some of the scenarios are oriented toward maintaining different aspects of system condition and performance or achieving a specified minimum level of performance, while others link to broader measures of system user benefits.

The capital investment scenario projections reflect complex technical analyses that attempt to predict the impact that capital investment may have on the future conditions and performance of the transportation system. **These scenarios are intended to be illustrative, and the Department does not endorse any of them as a target level of investment.**

This report does not attempt to address issues of cost responsibility. The investment scenarios predict the impact that particular levels of combined Federal, State, local, and private investment might have on the overall conditions and performance of highways, bridges, and transit.

In considering the system condition and performance projections in this report's capital investment scenarios, it is important to note that they represent what **could** be achievable assuming a particular level of investment, rather than what **would** be achieved. The models used to develop the projections generally assume that, when funding is constrained, the benefit-cost ratio (BCR) establishes the order of precedence among potential capital projects, with projects with higher BCRs being selected first. In actual practice, the BCR generally omits some types of benefits and costs because of difficulties in valuing them monetarily, and these other benefits and costs can and do affect project selection.

Also, some potential capital investments selected by the models, regardless of their economic merits or impact on conditions and performance, may be infeasible for political or other reasons. As a result, the supply of feasible cost-beneficial projects could be lower than the levels estimated by the modeling assumptions of some scenarios.

Chapter 9 provides supplemental scenario analyses, including comparisons of the investment requirements identified for selected scenarios in this report with those presented in previous editions. This includes a comparison of the 20-year projections from the 1991 C&P Report with what actually occurred in terms of VMT, conditions, and performance. Issues relating to the interpretation of scenarios, including the timing of future investment and the conversion of scenarios from constant dollars to nominal dollars, are also explored. Chapter 9 also discusses transit asset condition forecasts, transit PMT growth rates, the impact of new technologies on transit investment needs, and transit expansion investment.

The investment scenario projections in this report are based on assumptions about future travel growth and a variety of engineering and economic variables. The accuracy of these projections depends, in large part, on the realism of these assumptions. To address the uncertainty concerning which assumptions would be most realistic, Chapter 10 presents a series of sensitivity analyses that vary the discount rate, the value of travel time savings, and other economic assumptions, as well as some alternative system management strategies.

CHAPTER 7

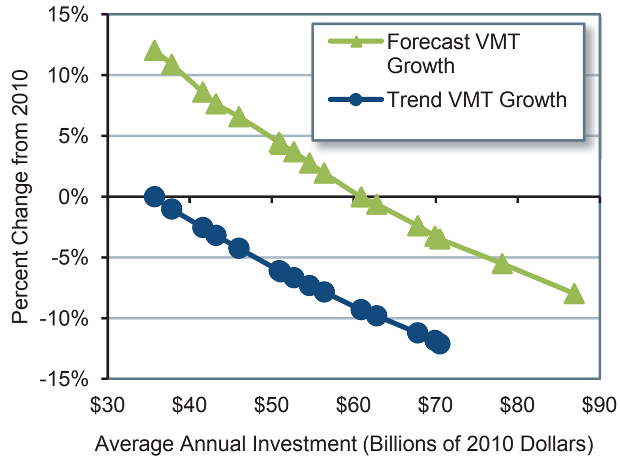
Potential Capital Investment Impacts: Highways

The rate of future travel growth can have a significant impact on the projected future conditions and performance of the highway system. For each of the more than 100,000 HPMS sample highway sections, States provide the actual base-year traffic volume and a forecast of future traffic volume. The HERS model assumes that these forecasts correspond to the VMT that would occur if the average user cost per mile of travel (including the costs of travel time, vehicle operation, and crash risk) remained unchanged. HERS then modifies the forecasts in response to projected future changes in user costs, increasing VMT if user costs rise or decreasing VMT if user costs fall. The composite weighted average growth rate computed from the 2008 HPMS sample data is 1.85 percent per year, which is reflected in the **forecast-based** analyses. An alternative set of **trend-based** HERS analyses was developed for this report in which the HPMS forecasts were modified to match the average annual VMT growth rate of 1.36 percent for the 15-year period from 1985 to 2010.

Of the $100.2 billion of total capital outlay by all levels of government combined in 2010, $56.4 billion was used on Federal-aid highways for types of capital improvements modeled in HERS, including pavement improvements and system expansion. Sustaining HERS-modeled investment at this level in constant dollar terms over 20 years is projected to result in a 1.9 percent increase in average delay per VMT and an 11.5 percent decrease in average pavement roughness by 2030 relative to 2010, assuming forecast-based VMT growth. Projected performance for 2030 relative to 2010 would be better assuming trend-based VMT growth, with average delay per VMT decreasing by 7.8 and average pavement roughness decreasing by 17.7 percent. The relatively greater improvement in pavement roughness assuming trend-based VMT growth is due partly to reduced pavement wear and tear associated with lower future VMT, but is due primarily to differences in the mix of investments recommended by HERS; the lower projected future VMT causes HERS to shift resources from capacity expansion to pavement improvements, resulting in better pavements.

Assuming forecast-based VMT growth, HERS projects that constant-dollar spending growth of 3.95 percent per year would suffice to finance all potentially cost-beneficial capital improvements on Federal-aid highways by 2030. This would translate into an average annual investment level of $86.9 billion and result in a 26.7-percent decrease in average pavement roughness and an 8.0-percent reduction in average delay per VMT. Assuming trend-based VMT growth, the pool of potential cost-beneficial investments would be smaller, and could be addressed if spending grew by 2.08 percent annually in constant-dollar terms, resulting in an average annual level of $70.5 billion.

Projected Change in 2030 Average Delay per VMT Compared With 2010 Levels, for Various Spending Levels Under Forecast and Trend VMT Growth



In 2010, $17.1 billion was spent on improvement types modeled in NBIAS, including bridge repair, rehabilitation, and replacement. Sustaining this level of investment in constant dollar terms over 20 years is projected to result in an increase in the average bridge sufficiency rating from 81.7 in 2010 to 84.1 in 2030 (on a 100-point scale). Increasing NBIAS-modeled constant dollar spending by 1.57 percent per year would translate to an average annual spending level of $20.2 billion, and would further improve the average sufficient rating to 84.6 by 2030.

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CHAPTER 7

Potential Capital Investment Impacts: Transit

In 2010, U.S. transit agencies spent a combined $16.5 billion on capital improvements to the Nation's transit infrastructure and vehicle fleets. This amount included $10.3 billion in the preservation (rehabilitation and replacement) of existing assets already in service and $6.2 billion to expand transit capacity—both to accommodate ridership growth and to improve performance for existing riders. Although 2010 investment levels are very similar to those of 2008, the proportion of capital funds used for expansion has increased from 32 to 38 percent and preservation investments have declined.

Sustaining transit capital spending at year 2010 levels for 20 years is projected to result in an overall decline in transit system conditions due to underinvestment in system preservation. The average physical condition of the Nation's stock of transit assets will decline, with an estimated 52 percent increase in the size of the "State of Good Repair" (SGR) backlog by 2030. The backlog is currently $85.9 billion. This will have impacts on service reliability and potentially on safety.

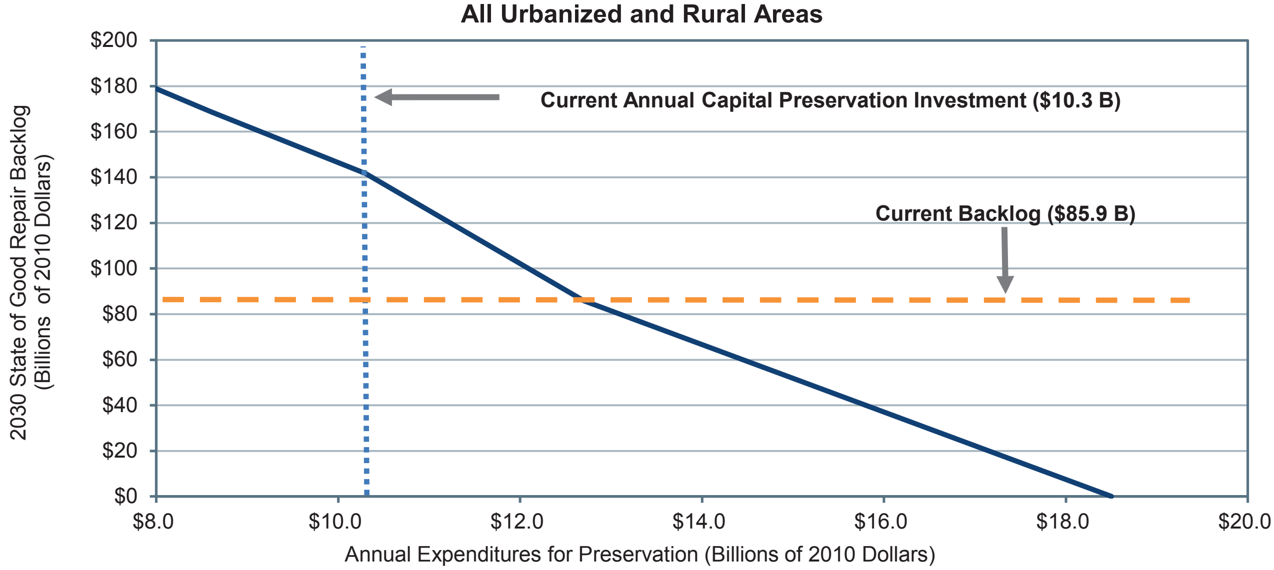
The TERM estimates that the average annual level of investment required to eliminate the existing system preservation backlog by 2030 is roughly $18.5 billion. Up to $7.1 billion in annual expansion investments may also be required to maintain transit performance (as measured by vehicle crowding) at 2010 levels, depending on the actual rate of growth in ridership.

However, current expansion rates seem sufficient to provide for expected levels of ridership growth. Continuing the current level of investment in expansion will result in somewhere between a 35-percent reduction and a 17-percent increase in vehicle occupancy by 2030 (depending on the magnitude of ridership growth).

Comparison of Current and Needed Annual Investment to Support Asset Preservation and Capacity Expansion in All Urbanized and Rural Areas

Current versus Needed Expenditures	Urbanized Areas with Populations > 1 Million	Urbanized Areas with Populations < 1 Million
Asset Preservation (Billions)		
2010 Expenditures	$9.0	$1.3
Annual Expenditures to Achieve SGR	$16.0	$2.5
Capacity Expansion (Billions)		
2010 Expenditures	$5.4	$0.9
Annual Expenditures Low Growth	$3.3	$0.2
Annual Expenditures High Growth	$5.4	$0.6

Impact of Preservation Investment on 2030 Transit State of Good Repair Backlog in All Urbanized and Rural Areas



CHAPTER 8

Selected Capital Investment Scenarios: Highways

This report presents a set of illustrative 20-year capital investment scenarios based on simulations developed using the HERS and the NBIAS models, with scaling factors applied to account for types of capital spending that are not currently modeled. The scenario criteria were applied separately to the Interstate System, the NHS, Federal-aid highways, and the highway system as a whole, based on section-level VMT forecasts from the HPMS averaging 1.85 percent per year. Separate versions of the scenarios for Federal-aid highways and all roads, assume lower, trend-based VMT growth of 1.36 percent per year. The **Sustain 2010 Spending** scenario assumes that capital spending is sustained in constant dollar terms at year 2010 levels from 2011 through 2030. (In other words, spending would rise by exactly the rate of inflation during that period.) Note that 2010 spending was supplemented by one-time funding under the Recovery Act. The **Maintain Conditions and Performance** scenario assumes that capital investment gradually changes in constant dollar terms over 20 years to the point at which selected measures of highway and bridge performance in 2030 are maintained at their year 2010 levels. For all roads, the average annual investment levels associated with this scenario are $86.3 billion assuming forecast-based VMT growth and $65.3 billion assuming trend-based VMT growth. Both estimates are below the $100.2 billion spent on all roads in 2010, indicating that sustained spending at 2010 levels could result in improved overall conditions and performance.

Unless one is completely satisfied with base year conditions and performance, investing at a level projected to maintain that level of performance would not yield an ideal result. The **Improve Conditions and Performance** scenario assumes that capital investment gradually rises in constant dollar terms to the point at which all potentially cost-beneficial investments could be implemented by 2030. This scenario can be thought of as an "investment ceiling" above which it would not be cost-beneficial to invest. The average annual investment level for all roads under this scenario is $145.9 billion for all roads assuming forecast-based VMT growth and $123.7 billion assuming trend-based VMT growth. Of the $145.9 billion **Improve Conditions and Performance** scenario investment level for all roads assuming forecast-based VMT growth, $78.3 billion (54 percent) would be directed toward improving the physical condition of existing infrastructure assets; this amount is identified as the **State of Good Repair** benchmark. The comparable values (assuming forecast-based VMT growth) for Federal-aid highways, the NHS, and the Interstate System are $60.4 billion, $34.5 billion, and $13.2 billion, respectively.

Average Annual Cost by Investment Scenario (Billions of 2010 Dollars)

System Subset	Sustain 2010 Spending	Maintain C&P	Improve C&P
Assuming Higher VMT Growth From HPMS Forecasts			
Interstate	$20.2	$17.4	$33.1
NHS	$53.9	$37.8	$74.9
FAH	$75.8	$67.3	$113.7
All Roads	$100.2	$86.3	$145.9
Assuming Lower Trend-Based VMT Growth			
FAH	$75.8	$50.3	$95.7
All Roads	$100.2	$65.3	$123.7

FAH=Federal-aid Highways; C&P=Conditions and Performance

Investing at the **Improve Conditions and Performance** scenario level for Federal-aid highways (assuming forecast-based VMT growth) is projected to result in a 26.7-percent reduction in average pavement roughness and an 8.0-percent reduction in average delay per VMT. The average bridge sufficiency rating is projected to rise from 82.0 to 84.7 under this scenario.

Of the $100.2 billion of highway capital spending on all roads in 2010, 27.4 percent was directed toward system expansion. Assuming forecast-based VMT growth, the **Sustain 2010 Spending** scenario for all roads would direct 29.9 percent of its investment toward capacity expansion; the comparable share for the **Improve Conditions and Performance** scenario is 33.6 percent.

CHAPTER 8

Selected Capital Investment Scenarios: Transit

This report presents a set of illustrative 20-year transit capital investment scenarios. These scenarios build upon analyses developed using the TERM and were applied separately to the Nation's transit assets as a whole, to urbanized areas (UZAs) with populations of more than one million, and to everyone else.

The Sustain 2010 Spending scenario assumes that capital spending is sustained at 2010 levels, in constant dollar terms, for 20 years. Transit operators spent $16.5 billion on capital projects in 2010. Of this amount, $10.3 billion was devoted to the preservation of existing assets and the remaining $6.2 billion was dedicated to investment in asset expansion to support ongoing ridership growth and to improve service performance. This scenario considers the expected impact on the Nation's transit infrastructure if these expenditure levels are sustained in constant dollar terms. TERM analysis suggests that sustaining spending at 2010 levels would likely yield an estimated 65-percent increase in the SGR backlog by 2030. The 2010 backlog is estimated at $85.9 billion. Current levels of expansion investment are within the projected range necessary to limit increases in crowding on transit passenger vehicles.

The **Low Growth** and **High Growth** scenarios consider the level of investment to address both asset SGR and service expansion needs subject to two differing potential levels of growth. The **Low Growth** scenario assumes that transit ridership will grow as projected by the Nation's metropolitan planning organizations, and the **High Growth** scenario assumes the average rate of growth (by UZA) as experienced in the industry since 1995. The **Low Growth** scenario assumes that ridership will grow at an annual rate of 1.4 percent during the 20-year period from 2010 to 2030; conversely, the **High Growth** scenario assumes that ridership will increase at a rate of 2.2 percent per year during that time frame. TERM estimates this average annual level of investment for the Nation to be between $22.0 billion and $24.5 billion, including between $17.3 billion and $17.4 billion to replace and rebuild assets as they exceed their life expectancy and between $4.6 billion and $7.1 billion for expansion to keep up with growth in demand. The high and low estimates here depend on the expected rate of ridership growth, which is expected to be between these high- and low-growth estimates.

Annual Average Cost by Investment Scenario (2010–2030)

Mode, Purpose, and Asset Type	Investment Projection (Billions of 2010 Dollars) Sustain 2010 Spending	SGR	Low Growth	High Growth
Urbanized Areas Over 1 Million in Population[1]				
Nonrail[2]: Preservation	$2.9	$4.6	$4.2	$4.2
Nonrail[2]: Expansion	$1.2	$0.0	$1.2	$2.1
Subtotal Nonrail[3]	**$4.1**	**$4.6**	**$5.4**	**$6.3**
Rail: Preservation	$6.3	$11.4	$11.0	$11.1
Rail: Expansion	$4.2	$0.0	$2.9	$4.0
Subtotal Rail[3]	**$10.5**	**$11.4**	**$13.9**	**$15.1**
Total, Over 1 Million in Population[3]	**$14.6**	**$16.0**	**$19.3**	**$21.4**
Urbanized Areas Under 1 Million in Population and Rural				
Nonrail[2]: Preservation	$1.1	$2.2	$1.9	$1.9
Nonrail[2]: Expansion	$0.6	$0.0	$0.5	$1.0
Subtotal Nonrail[3]	**$1.7**	**$2.2**	**$2.4**	**$2.9**
Rail: Preservation	$0.0	$0.3	$0.2	$0.2
Rail: Expansion	$0.2	$0.0	$0.0	$0.0
Subtotal Rail[3]	**$0.2**	**$0.3**	**$0.2**	**$0.2**
Total, Under 1 Million and Rural[3]	**$1.9**	**$2.5**	**$2.7**	**$3.1**
Total[3]	**$16.5**	**$18.5**	**$22.0**	**$24.5**

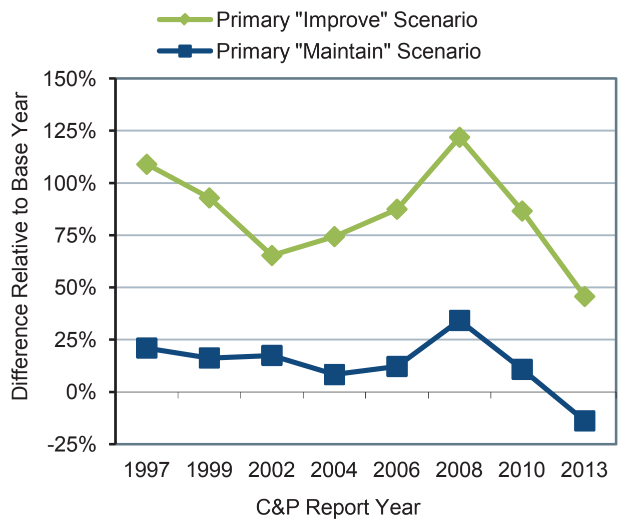
[1]Includes 37 different urbanized areas. [2]Buses, vans, and other (including ferryboats). [3]Note that totals may not sum due to rounding.

CHAPTER 9

Supplemental Scenario Analysis: Highways

While the names and definitions of the highway scenarios presented in the C&P report have varied over time, each edition has generally included one primary scenario oriented toward maintaining the overall state of the system and one oriented toward improving the overall state of the system. Looking at previous editions starting with the 1997 C&P Report, the "gap" between base year spending and the average annual investment level for the primary "Maintain" and "Improve" scenarios has varied, rising as high as 34.2 percent and 121.9 percent, respectively, in the 2008 C&P Report (comparing needs in 2006 dollars with actual spending in 2006). These larger gaps coincided with a 43.3 percent increase in construction costs between 2004 and 2006.

Gap Between Average Annual Investment Scenarios and Base Year Spending, as Identified in the 1997 to 2013 C&P Reports

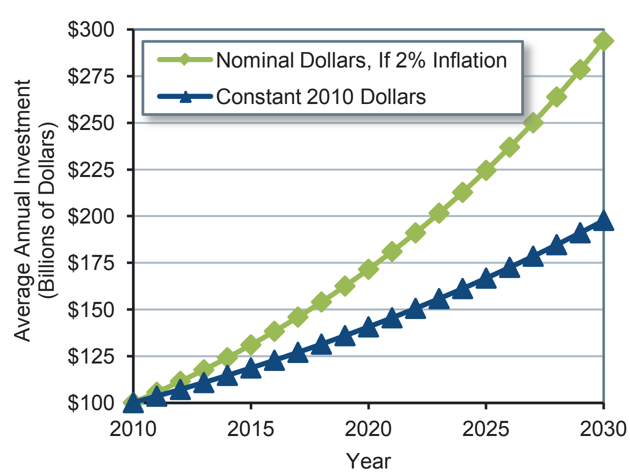


For the forecast-based analyses in the current 2013 C&P Report, the gap associated with the **Improve Conditions and Performance** scenario has fallen to 45.7 percent, while the gap with the Maintain Conditions and Performance scenario is –13.9 percent because the average annual investment level under the **Maintain Conditions and Performance** scenario is lower than actual spending in 2010. This negative gap is partially due to increased funding from the Recovery Act but is largely attributable to a recent decline in construction costs; the National Highway Construction Cost Index declined by 18.0 percent from 2008 to 2010.

For the 20-year period ending in 2028, the 2010 C&P Report estimated the average annual investment levels for the **Maintain Conditions and Performance** scenario and the **Improve Conditions and Performance** scenario to be $101.0 billion and $170.1 billion, respectively, both stated in constant 2008 dollars; restating this in 2010 dollars would reduce them to $82.8 billion and $139.4 billion. The comparable forecast-based values presented in the 2013 C&P Report for these scenarios ($86.3 billion and $145.9 billion) are **4.0 percent higher and 4.7 higher**, respectively, than these adjusted values.

The investment scenarios presented in this report are "ramped", applying an annual constant dollar growth rate starting with the $100.2 billion of highway capital spending by all levels of government in 2010. For the forecast-based **Improve Conditions and Performance** scenario, the amount spent in individual years ranges from $103.6 billion in 2011 (3.46 percent more than 2010 spending) up to $197.8 billion in 2030. These values do not reflect the effects of inflation; assuming a 2 percent annual inflation rate would increase the nominal dollar value for 2030 to $293.8 billion.

Illustration of Potential Impact of Inflation on the Improve Conditions and Performance Scenario



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CHAPTER 9

Supplemental Scenario Analysis: Transit

This section is intended to provide the reader with a deeper understanding of the assumptions behind the investment scenarios presented in Chapters 7 and 8. It includes discussion of the following topics:

- Asset condition projection under the four Chapter 8 scenarios.
- A comparison of 2010 to 2012 TERM results.
- A comparison of historic rates of growth in PMT with the growth projections provided by the Nation's MPOs.
- An assessment of the impact of an evident gradual transition to alternative fuel and hybrid vehicles on the reinvestment backlog.
- How many transit vehicles, route miles, and stations would be acquired under the **High Growth** and **Low Growth** scenarios.

Asset condition projections for each of the Chapter 8 scenarios are presented both as average condition ratings and as distributions of assets by how much of their useful life will have been consumed. The former includes a discussion of a more realistic (gradual) pay-down of the reinvestment backlog.

We then provide an analysis of the reasons that the SGR backlog estimate has changed relative to the projections presented in the 2010 edition of this report.

Causes of the Increase in the SGR Backlog between the 2010 C&P Report and the 2013 C&P Report

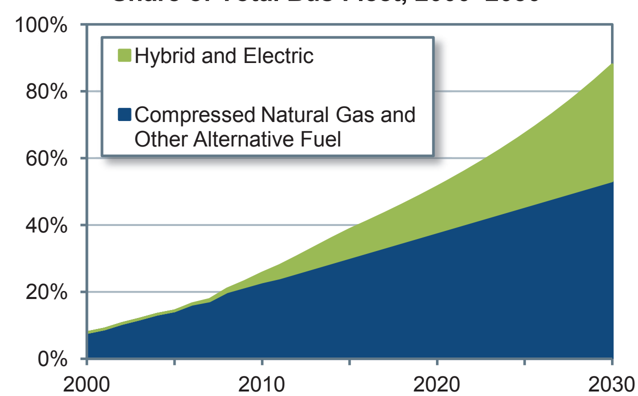
	Billion $
SGR backlog as reported in the 2010 C&P Report	$77.7
Impact of 2 additional years of needs	+9.0
Impact of inflation	+3.6
Impact from the change in the asset inventory	-4.4
SGR backlog as reported in the 2013 C&P Report	$85.9

This is followed by an analysis of average historical rates of transit PMT growth. These rates exceed the MPO-projected rates of growth typically used for long-range transportation planning purposes.

Given the difference between the two growth rates (and the relatively high rate of historic PMT growth as compared with other measures, such as UZA population growth), the 2.1-percent historical growth rate of PMT was identified as a reasonable input value for the **High Growth** scenario. Similarly, the 1.3-percent MPO-projected growth rate was used as an input value for the **Low Growth** scenario.

Based on recent trends in vehicle procurement, the share of vehicles powered by alternative fuels is estimated to increase from 23 percent in 2010 to 53 percent in 2030. During the same period, the share of hybrid buses is estimated to increase from 3 percent to 35 percent. The average cost of an alternative-fuel bus is 15.5 percent higher than that of a standard diesel bus of the same size, and hybrid buses cost roughly 65.9 percent more than standard diesel buses of the same size. An analysis of the impact these more expensive vehicles will have on long-term capital needs is presented in this section based on the assumption that these price differentials will remain static.

Hybrid and Alternative Fuel Vehicles: Share of Total Bus Fleet, 2000–2030



Finally, this section attempts to answer the question: what will our transit system look like in 2030 under these scenarios? In this discussion, fleet size, fixed guideway route miles, and the total number of stations under each scenario over the period of 2010 to 2030 is projected.

CHAPTER 10

Sensitivity Analysis: Highways

Critical to any modeling effort is evaluation of the underlying assumptions—their validity and the sensitivity of the modeling results to altering them. Chapter 10 demonstrates how the baseline forecast-based scenarios presented in Chapter 8 would be affected by changing some HERS and NBIAS parameters.

The valuation of travel time savings assumed in the baseline scenarios are linked to average hourly income; personal travel is valued at 50 percent of income, while business travel is valued at 100 percent. Alternative tests were run reducing these shares to 35 percent and 80 percent, respectively, and raising them to 60 percent and 120 percent. Applying a lower value of time reduces the benefits associated with travel time savings, and would reduce the average annual investment level under the **Improve Conditions and Performance** scenario from $145.9 billion to $134.9 billion, as some potential projects would no longer qualify as cost-beneficial. Assuming a higher value of time would increase the annual cost of this scenario to $153.3 billion.

The baseline scenarios assume a $6.2-million value of a statistical life for purposes of computing safety-related benefits. Reducing this value to $3.4 million would reduce the annual cost of the **Improve Conditions and Performance** scenario to $142.4 billion; increasing the value to $9.0 million would increase the annual cost to $148.9 billion.

Benefit-cost analyses use a discount rate that scales down benefits and costs arising further in the future relative to those arising sooner. The baseline scenarios assume a 7-percent rate; changing this to 3 percent would increase the average annual investment level under the **Improve Conditions and Performance** scenario to $177.3 billion.

The price of fuel assumed in HERS for the baseline scenarios is linked to the "reference forecast" from the Department of Energy's Annual Energy Outlook (AEO) publication. Substituting in values from the AEO "high oil price case" would increase the cost of driving, causing HERS to reduce its estimate of future VMT growth. This would reduce the annual cost of the **Improve Conditions and Performance** scenario to $124.5 billion.

The NBIAS Maintenance, Repair, and Replacement (MR&R) strategy assumed in the baseline scenarios aims to sustain bridges in a steady state. An alternative strategy of minimizing bridge MR&R costs was found to sharply increase bridge replacement needs in the long run, increasing average annual investment under the **Improve Conditions and Performance** scenario to $161.4 billion; even at this level of spending, it would not be possible to maintain the average bridge sufficiency rating at its 2010 level through 2030.

The baseline scenarios assume a continuation of current trends in deployments of Intelligent Transportation System (ITS)/Operations strategies. Accelerating these deployments would raise the cost of the **Improve Conditions and Performance** scenario, but would yield better results in terms of reducing average delay per VMT.

Impact of Alternative Assumptions on Highway Scenario Average Annual Investment Levels (Billions of 2010 Dollars)

Parameter Change	Maintain C&P	Improve C&P
Baseline	**$86.3**	**$145.9**
Lower Value of Time	$89.2	$134.9
Higher Value of Time	$84.9	$153.3
Lower Value of Statistical Life	$84.5	$142.4
Higher Value of Statistical Life	$87.7	$148.9
3 Percent Discount Rate	$88.1	$177.3
Higher Future Fuel Prices	$72.8	$124.5
Minimize Bridge MR&R Costs	N/A	$161.4
Aggressive ITS/Operations Deployments	$90.6	$151.5

MR&R=Maintenance, Repair, and Rehabilitation; C&P=Conditions and Performance

The impacts of alternative assumptions on the **Maintain Conditions and Performance** scenario are generally smaller, and linked either to the models' distribution of spending among different capital improvement types or to reduced VMT.

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CHAPTER 10

Sensitivity Analysis: Transit

The TERM relies on a number of key input values, variations of which can significantly impact the value of TERM's capital needs projections. Each of the three unconstrained investment scenarios examined in Chapter 8—including the **SGR** benchmark and the **Low Growth** and **High Growth** scenarios—assumes that assets are replaced at a condition rating of 2.50 as determined by TERM's asset condition decay curves. Analysis suggests that each of these scenarios is sensitive to changes in this replacement condition threshold, with the sensitivity increasing disproportionally with higher replacement condition thresholds. For example, reducing the condition threshold to 2.25 tends to reduce the SGR backlog by just over $1 billion (close to 6 percent). In contrast, increasing the threshold to 2.75 increases preservation needs by more than $3 billion (just under 20 percent), and a further threshold increase to 3.00 increases preservation needs by nearly $7 billion (around 40 percent). This increasing sensitivity reflects the fact that ongoing incremental changes to the replacement condition threshold yield greater proportionate reductions in the length of the asset life cycles as higher replacement condition values are reached.

Needs estimates for scenarios employing TERM's benefit-cost analysis are also particularly sensitive to changes in capital costs (assuming no comparable increase in benefits) because these increases tend to reduce the value of the benefit-cost ratio, causing some previously acceptable projects to fail this test. For example, a 25-percent increase in capital costs increases investment costs by more than $4 billion (about 20 percent) for the **Low Growth** scenario and by around $5 billion (almost 19 percent) for the **High Growth** scenario. In contrast, needs under the **SGR** benchmark (which does not utilize TERM's benefit-cost test) increase by less than $5 billion (25 percent) in response to a 25-percent increase in capital costs.

The most significant source of transit investment benefits as assessed by TERM's benefit-cost analysis is the net cost savings to users of transit services, a key component of which is the value of travel time savings. Consequently, the per-hour value of travel time for transit riders is a key driver of total investment benefits for scenarios that employ TERM's benefit-cost test. For example, a doubling of the value of time (from $12.50 per hour to $25 per hour) increases total needs for the **Low Growth** and **High Growth** scenarios by approximately $1 billion to $3 billion (7 to 10 percent) due to the increase in total benefits relative to costs. Similarly, a halving of the value of time decreases total investment needs for these scenarios by approximately $1 billion to $2 billion each (5 to 6 percent).

Finally, TERM's benefit-cost test is responsive to the discount rate used to calculate the present value of the streams of investment costs and benefits. For example, reducing the discount rate from the base rate of 7 percent to 3 percent yields an approximately $1-billion (3 to 6 percent) increase in total annual investment needs under the **Low Growth** and **High Growth** scenarios, respectively.

Impact of Alternative Replacement Condition Thresholds on Transit Preservation Investment Needs by Scenario (Excludes Expansion Impacts)

Replacement Condition Thresholds	SGR Benchmark		Low Growth Scenario		High Growth Scenario	
	Billions of 2010 Dollars	Percent Change From Baseline	Billions of 2010 Dollars	Percent Change From Baseline	Billions of 2010 Dollars	Percent Change From Baseline
Replace assets later (2.25)	$17.33	-6.1%	$16.00	-5.9%	$16.13	-5.8%
Baseline (2.50)	$18.46		$17.01		$17.12	
Replace assets earlier (2.75)	$22.07	19.6%	$20.16	18.5%	$20.41	19.2%
Very early asset replacement (3.00)	$26.03	41.0%	$23.28	36.9%	$23.49	37.2%

CHAPTER 11

Transportation Serving Federal and Tribal Lands

The Federal government holds title to approximately 650 million acres, or about 30 percent of the total land area of the United States. Additionally, the Federal government holds in trust approximately 55 million acres of land on behalf of Tribal governments. Federal lands are managed by various Federal land management agencies (FLMAs), primarily within the Departments of the Interior, Agriculture, and Defense. Federal lands have many uses, including the facilitation of national defense, recreation, grazing, timber and mineral extraction, energy generation, watershed management, fish and wildlife management, and wilderness maintenance.

More than 8 billion vehicle miles are traveled annually on the Tribal Transportation Program road system, with more than 60 percent of the system unpaved.

Recreation, national defense, travel, tourism, and resource extraction are all dependent on a quality transportation infrastructure. More than 450,000 miles of Federal roads provide access to Federal lands, which also provides opportunities for recreational travel and tourism, protection and enhancement of resources, and sustained economic development in both rural and urban areas.

More than 75 percent of Americans participate in active outdoor recreation each year, contributing $730 billion annually to the U.S. economy. These activities include hunting, fishing, wildlife viewing, biking, hiking, and water sports. In total, there are nearly 1 billion visits annually to Federal lands.

Many FLMAs are no longer able to meet the transportation demands placed upon them due to growing traffic volumes and demands for visitor parking at peak times. As population increases, the demand for access to Federal lands will continue to grow. For FLMAs to continue to fulfill their missions of providing visitor enjoyment and conserving precious resources, innovation and creative solutions will be required.

Economic Benefits of Federal Lands*

Federal Agency	Recreation Related Jobs	Recreation Economic Benefits ($ Billion)
Department of Agriculture		
Forest Service	205,000	13
Department of the Interior		
National Park Service	258,000	39
Fish and Wildlife Service	27,000	2
Bureau of Land Management	59,000	7
Department of Defense		
U.S. Army Corps of Engineers - Civil Works Facilities	270,000	16

** Economic benefits include lodging, food, entertainment, recreation, and incidentals expended during travel.*

Roads Serving Federal Lands

Agency	Public Paved Road Miles	Paved Road			Public Unpaved Road Miles	Public Bridges		Backlog of Deferred Maintenance
		Good	Fair	Poor		Total	Structurally Deficient	
Forest Service	10,700	25%	50%	25%	259,300	3,840	6%	$5.1 billion
National Park Service	5,450	60%	28%	12%	4,100	1,270	3%	$5 billion
Bureau of Land Management	700	60%	20%	20%	2,000	439	3%	$350 million
Fish & Wildlife Service	400	59%	23%	18%	5,200	281	7%	$1 billion
Bureau of Reclamation	762	N/A	N/A	N/A	1,253	311	11%	N/A
Bureau of Indian Affairs	8,800	N/A	N/A	N/A	20,400	929	15%	N/A
Tribal Governments	3,300	N/A	N/A	N/A	10,200	N/A	N/A	N/A
Military Installations	26,000	N/A	N/A	N/A	N/A	1,422	11%	N/A
U.S. Army Corps of Engineers	5,135	55%	25%	20%	N/A	294	11%	$100 million

CHAPTER 12

Center for Accelerating Innovation

America's transportation system faces unprecedented challenges. Aging roads and bridges are carrying greater traffic volumes and heavier loads than ever before and need extensive rehabilitation. Limited resources at transportation agencies across the country create the need to work more efficiently and focus on technologies and processes that produce the best results.

Addressing these challenges requires the transportation industry to pursue ways of doing business better, faster, and smarter. It requires harnessing the power of innovation to dramatically change the way highways are built. The Federal Highway Administration (FHWA) Center for Accelerating Innovation, established in 2011, provides national leadership on deploying innovation to meet today's transportation challenges. The center houses Every Day Counts—FHWA's initiative to shorten project delivery, enhance roadway safety, and protect the environment—and Highways for LIFE—the agency's initiative to build roads and bridges better, more safely, and with less impact on the traveling public.

Every Day Counts

The Every Day Counts initiative, launched in 2009, has two key components. The first is accelerating technology and innovation deployment. This involves identifying market-ready technologies that can benefit the highway system and accelerating their widespread use. Within the first 2 years of this initiative, 34 States had adopted Safety Edge℠ as a standard for paving projects, 45 States were in various stages of implementing warm-mix asphalt, 44 States were implementing adaptive signal technology, 675 replacement bridges had been designed or constructed using prefabricated bridge elements and systems, and 85 geosynthetic reinforced soil integrated bridge systems had been designed or constructed.

The second key component of Every Day Counts is shortening project delivery. Within the first 2 years of this initiative, 56 programmatic agreements (which establish streamlined processes for handling routine environmental requirements on common project types) were initiated. Thirteen States had active mitigation banking agreements (for restoring or enhancing wetlands, streams, or other resources to offset unavoidable adverse impacts related to a highway project in another area.) During these 2 years, more than 220 projects were designed and constructed using the design-build or construction manager–general contractor project delivery methods.

Selected Every Day Counts Initiatives

Accelerating Technology and Innovation Deployment

- Adaptive Signal Control Technology
- Geosynthetic Reinforced Soil Integrated Bridge Systems
- Prefabricated Bridge Elements and Systems
- Safety Edge℠
- Warm-Mix Asphalt

Shortening Project Delivery Toolkit

- Eliminate Time-Consuming Duplication Efforts
- Encourage Use of Existing Regulatory Flexibilities

Accelerated Project Delivery Methods

- Design-Build
- Construction Manager–General Contractor

Highways for LIFE

FHWA began to address the critical need for rapid innovation through Highways for LIFE, a pilot program established in 2005 with three goals: to improve safety during and after construction, to reduce congestion caused by construction, and to improve the quality of highway infrastructure.

From fiscal years 2006 to 2012, the program provided incentives totaling about $65 million for 70 projects, including innovations such as accelerated bridge construction techniques, precast concrete pavement systems, and new contracting methods.

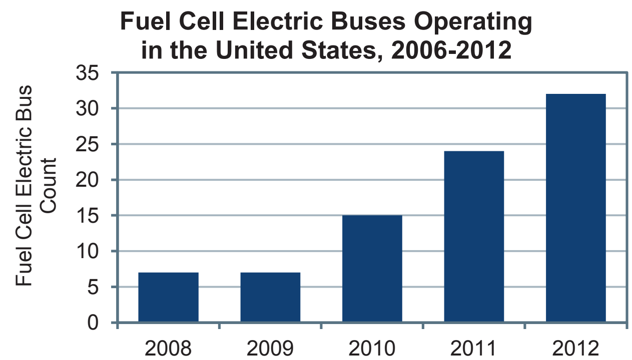
CHAPTER 13

National Fuel Cell Bus Program

This chapter summarizes the accomplishments of fuel cell transit bus research and demonstration projects supported by the FTA through 2011. It describes fuel cell electric bus (FCEB) research projects in the United States and describes their impact on commercialization of fuel cell power systems and electric propulsion for transit buses in general.

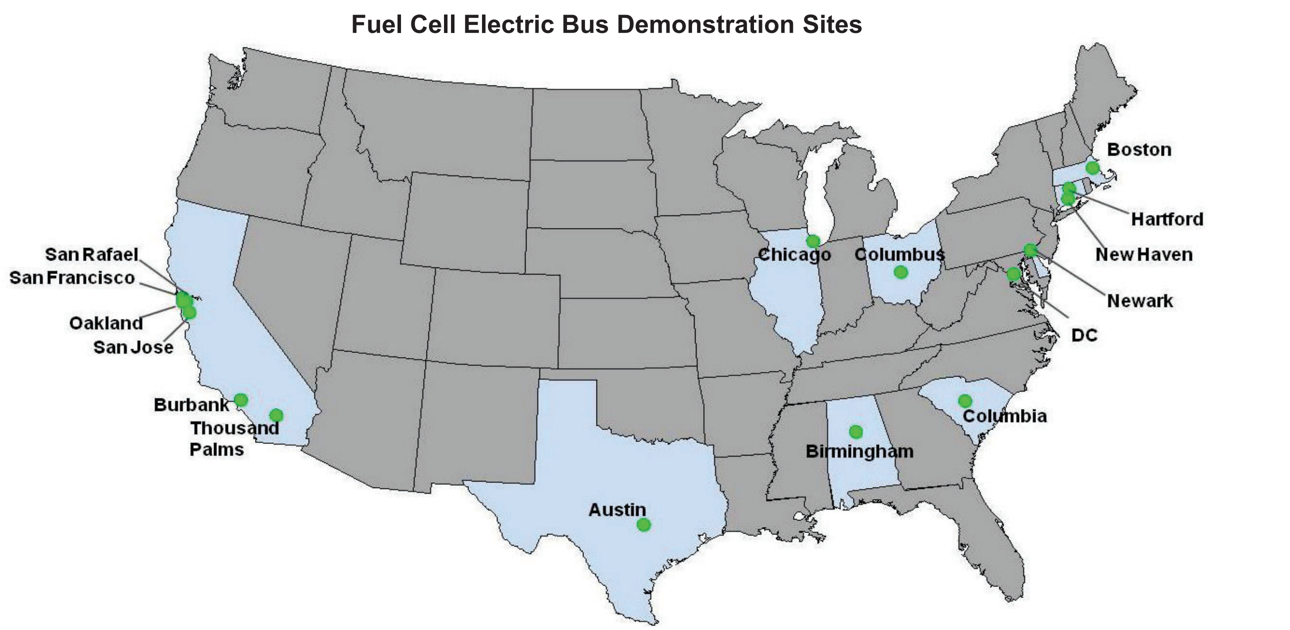
FTA sponsors the National Fuel Cell Bus Program (NFCBP), a cooperative research, development, and demonstration program to advance commercialization of FCEBs. The NFCBP is a part of a larger FTA research program to improve transit efficiency and contribute to environmentally sustainable transportation. NFCBP projects target research to improve performance and lower costs of next-generation fuel cell systems for transportation.

FTA's research to develop FCEBs has been underway since 2006. NFCBP projects require a dollar-for-dollar cost share for Federal funds, bringing the size of the program to more than $150 million through FY 2011.



NFCBP accomplishments include:

- Supporting an El Dorado–BAE Systems–Ballard partnership that developed and demonstrated a new FCEB at SunLine and CTA. The new bus meets Buy America requirements and is assembled in Riverside, CA.
- Canadian-based fuel cell manufacturer Ballard Power Systems has established manufacturing capabilities for fuel cell power systems in Lowell, MA.
- The NFCBP funded a project with Connecticut-based fuel cell manufacturer UTC Power to engineer, package, and test a fuel cell power system that can be installed easily into U.S. bus manufacturer models.



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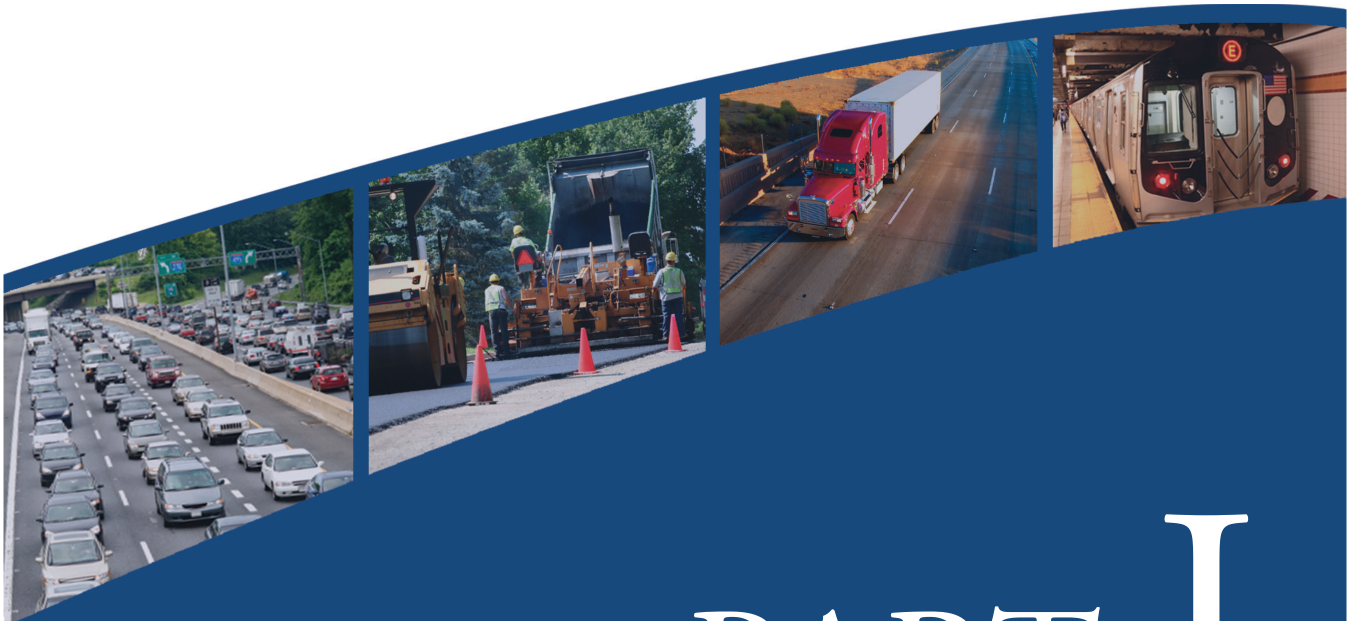


PART I

Description of Current System

Introduction

Part I of the C&P Report, Chapters 1 through 6, present data on the condition and performance of the highway and transit systems, travel behavior, and funding trends. Data are presented for 2010, with comparisons to the 2008 data and the past 10 to 20 years. Data for each year are to be interpreted in the context of the economic and social environment prevalent at the time. Part I, Introduction, presents the background context to the data to be discussed in the following chapters.

Chapter 1, **Household Travel and Freight Movement**, outlines the trends in travel behavior of households and businesses. The results of the 2009 National Household Travel Survey are discussed in particular, examining the level of travel, time of travel, and mode of travel. Aging of the population and the vehicle fleet are discussed in some detail. Using the data of the travel survey, some of the myths of travel are disputed, for example that the majority of personal travel is for commuting to work. A section on trends in freight travel is added to discuss the trends and issues facing the business community in moving goods across the country to support the diverse and growing economy.

Chapter 2, **System Characteristics**, describes the highway, bridge, and transit systems, presenting the extent and the types of infrastructure in the United States, as well the ownership and geography.

Chapter 3, **System Conditions**, presents the data on the condition of the highways, bridges, and transit systems and vehicles in 2010. The 2010 condition is compared to the 2008 condition data and also to earlier periods, by system purpose, jurisdiction, and geography.

Chapter 4, **Safety**, illustrates the safety data on fatalities and injuries for highways and transit for different modes of travel—motor vehicles, pedestrians, non-motor vehicles and transit systems, and functional class of roads. It discusses the factors contributing to crashes on highways related to roadway design and functionality, as well as human behavior.

Chapter 5, **System Performance**, discusses the data and performance measures for system performance. System performance is defined broadly to include the implication of transportation usage and construction on the environment, land use, and economic competitiveness. It discusses performance measures for livability, environmental sustainability, and economic competitiveness, outlining some initiatives for livability and sustainability and the trends in national congestion and travel time reliability.

Chapter 6, **Finance**, provides detailed data on the revenue collected and expended by different levels of government to fund transportation construction and operations throughout the United States. The trends in the data are discussed, providing a context where appropriate.

U.S. DOT Strategic Plan

In 2012, the U.S. DOT developed a 4-year Strategic Plan 2012-16, outlining the objectives and performance goals for the Nation's transportation system. The U.S. DOT identified five strategic goals that each agency promotes through its programs.

Safety – Improve public health and safety by reducing transportation-related fatalities and injuries.

State of Good Repair – Ensure that the United States proactively maintains its critical transportation infrastructure in a state of good repair.

Economic Competitiveness – Promote transportation policies and investments that bring lasting and equitable economic benefits to the Nation and its citizens.

Livable Communities – Foster livable communities through place-based policies and investments that increase the transportation choices and access to transportation services.

Environmental Sustainability – Advance environmentally sustainable policies and investments that reduce carbon and other harmful emissions from transportation sources.

Each agency identified specific measures and targets for the goal areas, as appropriate and feasible. For instance, for the goal area of safety, the desired outcome is reduced transportation-related fatalities and injuries, which is measured differently by each mode. One of the measures used for highways is the number of fatalities per million vehicle miles traveled (VMT), referred to as the fatality rate. There is a rich database for this measure, which makes it possible to understand the trends over time and to identify some of the underlying factors that may influence it. This allows the agencies to set future targets and to identify strategies to reach the target.

For some of the goals, the outcome depends on the actions of multiple agencies or even multiple departments. For instance, to reduce the crash rate on roads, it may be necessary to redesign the road, change driving behavior—for example, banning use of phones while driving—or requiring additional training and licensing standards for drivers. An achievement of this goal requires concerted effort from three agencies: FHWA, National Highway Traffic Safety Administration (NHTSA) and Federal Motor Carrier Safety Administration (FMCSA). Achieving the livability outcomes require coordination among FHWA, Federal Transit Administration (FTA), and U.S. Department of Housing and Urban Development (HUD). Often, legislation can influence the products that the private sector develops in response to greater awareness of issues. Motor vehicles have become safer over time as consumers demand greater safety.

Each chapter in this edition of the C&P report pertaining to the goal areas above discusses the performance measures and targets identified in the U.S. DOT's Performance Plan for Fiscal Year 2013. The discussion includes the challenges of selecting the appropriate measure, the limitations of the data currently available, and research into developing useful measures. Chapter 3, System Conditions, discusses the performance measures for the state of good repair for pavement and bridges; Chapter 4, Safety, discusses the measures for safety; and Chapter 5, System Performance, discusses performance measures relating to economic competitiveness, livability, and environmental sustainability.

Performance Management

For many decades, the biennial C&P report has provided data on the condition and performance of the highway and transit systems in the United States, informing Congress and the public of the status of the Nation's transportation infrastructure. However, the need for Government accountability and transparency has increased over the last decade. To address this need, many government agencies in the United States and abroad have adopted the practice of performance management.

Performance management is by no means a new concept to the transportation sector. Many States and Metropolitan Planning Organizations (MPOs) already use performance management in transportation planning and programming, as do many other countries, see report from the FHWA International Technology Scanning Program, Linking Transportation Performance and Accountability, April 2010 (http://www.international.fhwa.dot.gov/pubs/pl10011/pl10011.pdf). According to the PEW Center's report of May 2011 (Measuring Transportation Investments – Roads to Results), many States have adopted key elements of performance management such as performance goals, measures, and data that provide their policy makers with information to use for making funding decisions. Other States may be in earlier stages of developing performance goals, measures, and data. The U.S. Department of Transportation (DOT) has introduced some elements of performance management into its operations through its FY 2012-2016 Strategic Plan, and in July 2012 the Moving Ahead for Progress into the 21st Century Act (MAP-21) (P.L. 112-141) introduced requirements that have reinforced the importance of performance management for transportation investment decisions.

What is Performance Management of the Federal Transportation Program?

Transportation Performance Management (TPM) is a strategic approach that uses system information to make investment and policy decisions to achieve national performance goals. A typical performance management planning and programming process is likely to follow the practice in *Exhibit I-1*. First, establish a set of goals/objectives to be achieved by the program—these could be general in nature, such as improving safety on the highway system. Second, define measures that support the goal or objective. For safety, this could be the number of crashes or more specifically fatalities. Third, define the measure to be used. Data for the measure and other influencing factors are collected over a period of time to determine the current status, how it has changed over time, and what factors influence its trend. This information can be used to identify actions that are likely to influence the measure trend. Fourth, establish specific future targets for the measure. The specific targets for the measure can be aspirational, based on past trends, or fiscally constrained. Then, specific plans, budgets, and programs are developed to support the desired outcome. Fifth, report the results. After the programs are implemented, the results from the action/investment are assessed against the desired goal. Any discrepancy between the planned outcome and the actual outcome can be addressed by altering strategies and priorities. Performance management is a continual improvement process.

A performance management program for the Federal-aid program will enable States and MPOs to focus on common national goals, targeting investments towards areas of national significance. Tracking performance measures against specific targets helps inform decision makers about how well the current investments are moving the agencies toward achieving national goals. Performance management makes investment decisions more transparent and increase accountability as results are tracked.

Selection of Performance Measures

Performance measures can be either output based or outcome based. An output-based performance measure tracks the quantity of activity undertaken. For instance, the number of lane miles constructed in 3 years is an output measure; it does not tell you how the activity affects the condition or performance of the transportation system. An outcome measure would identify the impact of the action or activity on condition or performance of the system. An example would be the percentage of pavement in good condition. An agency may track both types of performance measures. The output measures would be used to inform the agency what actions/activities are undertaken to influence the performance outcome. If the current actions do not achieve the desired outcome, they should be reconsidered or new actions adopted. The focus of performance management is on the outcome.

An effective performance measure needs to directly relate to the investment decisions of the agency. It has to be a measure that the agency can influence and for which the agency can be held accountable. For instance, pavement reconstruction will improve the condition of the system, but increasing U.S. exports is not something a Department of Transportation (DOT) can influence directly because it depends on the investment and decisions of many other parties. Additionally, the measure needs to be easily understood by the public and not be too complex or costly to create or track. In addition, the measure is to be outcome based and change over a relatively short period of time so that the effectiveness of the actions can be tracked.

Exhibit I-1 Performance Management Planning and Programming Elements

Elements	Description	Examples
Strategic Direction (Where do we want to go?)		
Goals and objectives	Goals and objectives that capture an agency's strategic direction	Infrastructure condition, safety, mobility, reliability, and other goals established by an agency.
Performance measure	Agreed on measures for goals and objectives.	Percent of bridges in good condition, travel time index, and other measures linked to agency goals.
Long-Range Planning (How are we going to get there?)		
Identify targets and trends	Establish aspirational targets or preferred trends based on an understanding of a desirable future for each goal area and measure.	Desired conditions of pavement, bridge, and transit assets. Desired future corridor travel times or reliability levels. Desired future crash, injury, and fatality reductions.
Identify strategies	Strategies, policies, and investments that address transportation system needs within the identified goal areas.	Resurfacing, rehabilitation, replacement, and reconstruction to support infrastructure condition. Signal timing, vehicle maintenance, service patrols, additional capacity (transit or highway), tolling, and other strategies/investments to improve mobility or reliability. Seat belt or drunk driving enforcement, graduated drivers licenses, rumble strips, training, median barriers, and other investments to improve safety.
Strategy evaluation	Evaluate strategies and define program level system performance expectations, may be qualitative.	Examine impact of varying levels of investment on pavement and, bridge preservation and transit assets. Examine impact of packages of operations, capacity and other highway or transit investments on corridor travel time and/or reliability. Examine potential for reduction in crashes, injuries, and fatalities from a package of safety investments.
Programming (What will it take?)		
Investment plan	Identify the amount and mix of funding needed to achieve performance goals within individual program areas.	Investment plan for pavement, bridge, transit asset, operations, expansion, safety, and other projects consistent with strategy evaluation, including specific projects and high-level summary of expected investment levels.
Resource constrained targets and trends	Established quantitative or qualitative targets or desired trends for each goal/measure.	Expected future conditions of pavement and bridge conditions and transit assets. Expected future corridor travel times or reliability improvements given a package of investments. Expected range of crash, injury, and fatality reduction from a package of safety investments.
Program of projects	Identify specific transportation projects for an agency capital plan, or State/ Transportation Improvement Program (S/TIP) that are consistent with system performance expectations established in strategy evaluation.	S/TIP with specific projects identified in major program areas (pavement, bridge, transit assets, capital, operations, safety, etc.).
Implementation and Evaluation (How did we do?)		
Reporting and monitoring	Monitor progress on goals relative to targets and resource allocation efforts.	Report on pavement, bridge, transit assets, reliability, safety, and other metrics presented to stakeholders, public, and decision makers.
Evaluation	Identify improvements in analytics, process, etc. to improve the planning process. Evaluating the mix of projects.	Examine actual conditions relative to expected conditions for assets, reliability, safety, and other areas. Identify where tools produced inaccurate estimates or investments and policies were more or less successful than planned.

Source: Performance Based Planning and Programming, White Paper, FHWA, 2012.

MAP-21 Performance Management Requirements

MAP-21 introduced specific requirements for performance management for Federal highway and transit funding programs, reinforcing the use of performance management for Federal surface transportation investments. MAP-21 established national goals for transportation, directed U.S. DOT to establish performance measures for each of the goal areas, and requires States to set performance targets for each of the measures and report the outcomes to U.S. DOT to track progress. The national goals are:

- Safety
- Infrastructure Condition
- Congestion Reduction
- System Reliability
- Freight Movement and Economic Activity
- Environmental Sustainability
- Reduced Project Delivery Delay.

Federal Agencies are required to define the measures and standards for achieving the goals identified, unless defined in MAP-21. The States are to determine their own targets to achieve, while minimum standards may be established by Federal agencies where appropriate. The States are required to develop risk-based asset management plans, safety plans, and freight plans. The 20-year, long-range plans are expected to be performance based.

States are to report progress toward the targets established. Failure to meet targets or develop plans has specific penalties for States – reduction in funding or requirements to spend more on the specific goal area. For instance, failure to develop or implement a risk-based asset plan would result in the Federal share payable on account of any project or activity carried out by the State in that year for infrastructure of only 65 percent. If fatality rates on rural roads increase over the recent 2-year period, the State is required to obligate a minimum of 200 percent of the received funds for FY 2009 high-risk rural roads. States are to report progress toward the targets within 4 years of enactment of MAP-21, and biennially thereafter.

Transit agencies that receive FTA grant funds are similarly required to maintain asset management plans, to set goals for achieving a state of good repair, and to report asset inventory condition data to FTA along with metrics demonstrating their progress toward meeting their goals. MAP-21 also established a comprehensive transit safety program at FTA and the States to assist and monitor transit agencies as they strive to eliminate accidents.

CHAPTER 1

Household Travel and Freight Movement

Household Travel

To fully understand daily travel, one must look at it through the lens of the 300 million Americans who are using the transportation system to connect to their jobs, markets, educational facilities, healthcare services, airports, recreational places, and more. The National Household Travel Survey (NHTS) is unique in that it is the only national source of travel data that connects the characteristics of the trip (e.g., mode used, trip purpose, distance) with the characteristics of the household (e.g., income, vehicle ownership, location) and of the individual making the trip (e.g., age, sex, education, worker status). As such, it allows for observation of daily travel behavior and fluctuations in that behavior through the lens of socio-demographic and economic changes in the country. The 2009 NHTS, the most recent survey, was sponsored primarily by the Federal Highway Administration (FHWA), with participation by the Federal Transit Administration (FTA), the American Association of Retired Persons (AARP), and American Automobile Association. The FHWA Office of Highway Policy and Information serves as the project manager for the survey.

It is crucial to understand travel behavior in the context of demographics and location. The average transportation project has a 20-year span from definition of potential need to full completion. The more the relationship between travel behavior and the demographics of the public and the location of homes and workplaces can be documented, the better future needs can be determined and resources effectively used. This chapter describes some elements of how travel is changing as the Nation is changing.

Since 1969, NHTS has collected personal travel information intermittently using a national sample of households in the civilian noninstitutionalized population. The survey captures a snapshot of the American public's daily travel behavior. It is crucial that the information used to guide policies that impact our transportation system is based on sound statistical data, such as that from the NHTS. The 2009 NHTS data were collected from March 2008 through April 2009, which covered a period when there was a drop in vehicle miles of travel and, in some places, an increase in transit use.

This section contains a discussion of the recent decline in vehicle miles traveled (VMT), the disparity of this decline in urban versus rural areas, and how the decline differed by trip purpose. The section also contains a comparison of the usual mode of travel to work with the actual mode used, the influence of the Baby Boomers on total travel, and the aging of the household vehicle fleet. Five commonly held myths about travel are discussed,

NHTS Methodology and Timing

The NHTS collects travel data from a representative sample of U.S. households to characterize personal travel patterns. The survey obtains demographic characteristics of households and people and information about all vehicles in the household. Details of travel by all modes for all purposes of each household member are collected for a single assigned travel day. In this way, NHTS traces both the interaction of household members and the use of each household vehicle throughout an average day. The data provide national and, with the 2009 survey, State-level estimates of trips and miles by travel mode, trip purpose, time of day, gender and age of traveler, and a wide range of attributes.

Much of the data presented in this section are from the NHTS data series, unless otherwise noted. Since 1990, NHTS data have been collected using a random-digit dial sample of telephone households in the United States. Prior to 1990, NHTS data were collected in face-to-face interviews sampled from respondents to the Census Bureau's Current Population Survey.

The 2008–2009 NHTS data were collected during a time when the price of gas was hitting a peak of $4 per gallon, unemployment was on the rise, the stock market was falling, and the housing market was declining. The survey results, particularly the decline in household-based vehicle miles traveled (VMT), should be considered against this backdrop. Note that the previous survey in the series, the 2001 NHTS, was also conducted during an economic downturn.

Additional information on NHTS is available at www.fhwa.dot.gov/policyinformation/nhts.cfm or http://nhts.ornl.gov.

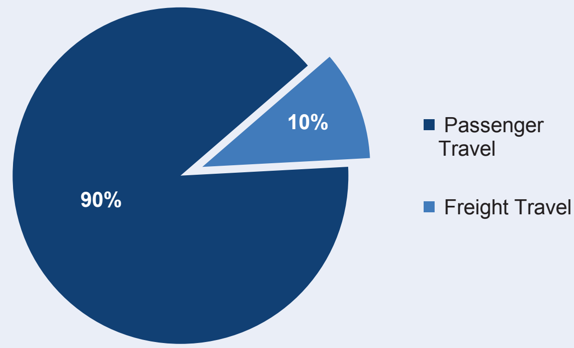
How do the NHTS-derived VMT figures in this Chapter differ from the HPMS-derived VMT figures presented elsewhere in this report?

One key difference is that NHTS does not include freight VMT. Freight movement is discussed later in this Chapter.

The NHTS collects data by interviewing American households and, as such, it differs from the Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS), which is a primary source for data in many other chapters of this report. HPMS collects data on extent, condition, performance, use, and operating characteristics of the Nation's public roads directly from State DOTs. The NHTS data, collected by survey, provide detail on individual and household travel characteristics that is not available from the HPMS data. NHTS also reflects personal travel, not including freight movements and other commercial travel; HPMS is designed to count all travel, both passenger and freight. *Exhibit 1-1* depicts the approximate split of VMT between passenger (personal) and freight.

NHTS and HPMS data are deliberately collected to be independent estimates of travel in the United States. Analysis of differences between the two sources is performed for quality control. Note that the one linkage between these two sources is that vehicle occupancy from the NHTS is used in computing person miles of travel for HPMS.

Exhibit 1-1 VMT by Type of Travel



Source: Highway Statistics 2008, Table VM-1.

and the chapter concludes with a discussion of the public's opinions of travel issues and the related gas price spike in the summer of 2008.

This portion of Chapter 1 presents some of the trends in travel behavior that can be gleaned from the NHTS data. The data allow for analysis of other topics and issue areas as well as tabulations at the national and local levels. As technology continues to impact communications and transportation, the need to track the intersection of demographics and travel behavior increases.

Trends in Our Nation's Travel

The NHTS results show a consistent increase in VMT during the three-decade period from 1969 through 2001 but a decrease in VMT between 2001 and 2009. As shown in *Exhibit 1-2*, the total number of trips has increased over time from 1990 through 2009, but household VMT decreased between 2001 and 2009.

Exhibit 1-2 Summary Statistics on Total Travel, 1990–2009 NHTS (Millions)

	1990	1995	2001	2009
Household Vehicle Trips	193,916	229,745	233,030	233,849
Household VMT	1,695,290	2,068,368	2,274,769	2,245,111
Person Trips	304,471	378,930	384,485	392,023
Person Miles of Travel	2,829,936	3,411,122	3,783,979	3,732,791

Notes:

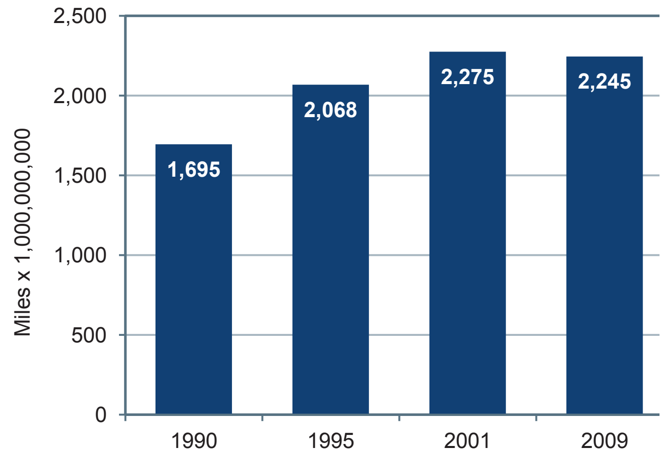
1. The travel of children aged 0-4 is excluded from 2001 NHTS data to make it comparable with other years.
2. 1990 person and vehicle trips were adjusted to account for survey collection method changes.
3. Vehicle miles and person miles are only calculated on trips with distance reported.

Source: NHTS data series. See 2009 NHTS Summary of Travel Trends, Table 1.

Americans drove 30 billion fewer vehicle miles in 2008-2009 than in the 2001-2002 NHTS survey period, as shown in *Exhibit 1-3*, even though the population grew by almost 10 percent during that period.

The NHTS results also show that transit ridership increased by 16 percent from 2001 to 2009, far outstripping the population growth during that time period. Most of the increase in transit use was for shopping and social/recreational activities other than visiting friends and relatives. This category includes going to movies, plays, restaurants, sporting events, and recreational activities like playing sports and going to the gym.

Exhibit 1-3 Total Annual Household VMT (Billions)



Note: The travel of children aged 0–4 is excluded from 2001 NHTS data to make it compatible with other years.

Source: NHTS data series.

Geographic Trends in Trip Rates and Trip Lengths

Two basic factors used in land use planning and travel demand forecasting are where people live and where they work. Each time people leave their places of residence, work places, or elsewhere, they generate a "trip," and the distance traveled and other attributes of the trip are captured in the survey.

As reflected in *Exhibit 1-4,* daily travel shows a steady increase from 1969 to 2001. Daily person trips peaked in 1995 at 4.30 trips per person per day. Daily miles per person showed a slightly different pattern, peaking in 2001 at 40.25 miles per person per day and declining to 36.13 miles per person per day in 2009. The average person trip length also decreased in 2009 when compared to 2001; average person trip length in 2001 was 10.04 miles and in 2009 it was 9.75 miles, which reduced the average person trip by

Exhibit 1-4 Summary of Daily Travel Statistics, 1969–2009 NHTS

	1969	1977	1983	1990	1995	2001	2009
Per Person							
Daily Person Trips (count)	2.02	2.92	2.89	3.76	4.3	4.09	3.79
Daily PMT (miles)	19.51	25.95	25.05	34.91	38.67	40.25	36.13
Per Driver							
Daily Vehicle Trips (count)	2.32	2.34	2.36	3.26	3.57	3.35	3.02
Daily VMT (miles)	20.64	19.49	18.68	28.49	32.14	32.73	28.97
Per Household							
Daily Person Trips (count)	6.36	7.69	7.2	8.94	10.49	9.81	9.5
Daily PMT (miles)	61.55	68.27	62.47	83.06	94.41	96.56	90.42
Daily Vehicle Trips (count)	3.83	3.95	4.07	5.69	6.36	5.95	5.66
Daily VMT (miles)	34.01	32.97	32.16	49.76	57.25	58.05	54.38
Per Trip							
Average person trip length (miles)	9.67	8.87	8.68	9.47	9.13	10.04	9.75
Average vehicle trip length (miles)	8.89	8.34	7.9	8.85	9.06	9.87	9.72

Notes:

1. Average trip length is calculated using only those records with trip mileage information present.

2. 1990 person and vehicle trips were adjusted to account for survey collection method changes.

Source: NHTS data series.

approximately one-quarter of a mile. On the surface, one-quarter of a mile may not appear to be considered significant, but when you multiply it by more than 3 billion person trips, the results become notable.

Examining trends by geographic location can provide a better understanding of where these changes are occurring. In 2009, the data showed that there was a significant decrease in passenger trips and passenger miles in both urban and rural areas compared to 2001 (see *Exhibit 1-5*).

However, residents of urban areas reduced their person trips and person miles of travel more than those living in rural areas. For every decrease of one person trip in rural areas, there was a decrease of two person trips in urban areas. In addition, per capita, there was about a 14.5-percent overall decrease in person miles. In urban areas, the largest person-mile decrease happened at slightly less than 17 percent, whereas there was about a 10 percent decrease in rural areas.

NHTS Terminology

Trip Chain or Linked Trip – Individual trips or trips that are linked together to a destination. Any movement from one address to another, except if only to change mode of transport.

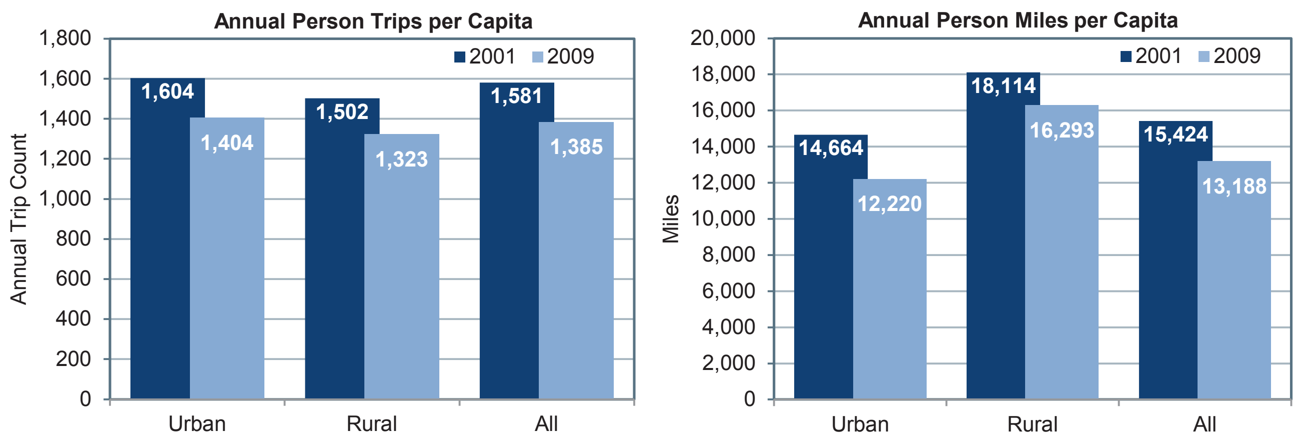
Person Trip – Any trip made by one person regardless of mode (auto, truck, transit, walk, bike, etc.).

Person Miles of Travel – The miles associated with a person trip.

Vehicle Trip – Any movement of a vehicle from one address to another, regardless of the number of vehicle occupants.

Vehicle Miles Traveled (VMT) – The miles associated with a vehicle's movement, regardless of the number of occupants.

Exhibit 1-5 Annual Person Trips and Person Miles per Capita by Urban/Rural Residence



Note: The travel of children aged 0–4 is excluded from 2001 NHTS data to make it compatible with other years.

Source: 2001 and 2009 NHTS.

Despite increases in aggregate personal VMT through 2001, a number of indicators point toward saturation in vehicle trips and vehicle miles of travel per person, with the peak of most per-person and per-household statistics occurring in 1995. Several factors could be possible explanations for this apparent saturation, such as the desire to limit the time spent in travel and replacing physical trips with electronic communication or online shopping. Given both the gas price spike in the summer of 2008 and the economic recession starting in autumn of that year, it is difficult to isolate how much of the reduction in travel was the product of these two events and how much was the product of broader changes. The proposed 2015 NHTS will add a crucial data point for continuing to track trends in travel behavior.

The Determinants of Travel

The NHTS is the only national data source that asks the American public why they took a given trip. The purpose of travel is significant because it provides a tool for anticipating travel volumes and demand given predictions of demographic change. Purposes are classified into a number of categories: to work, for work-related business, to shop, to run family or personal errands, to school or church, and to make social or recreational trips.

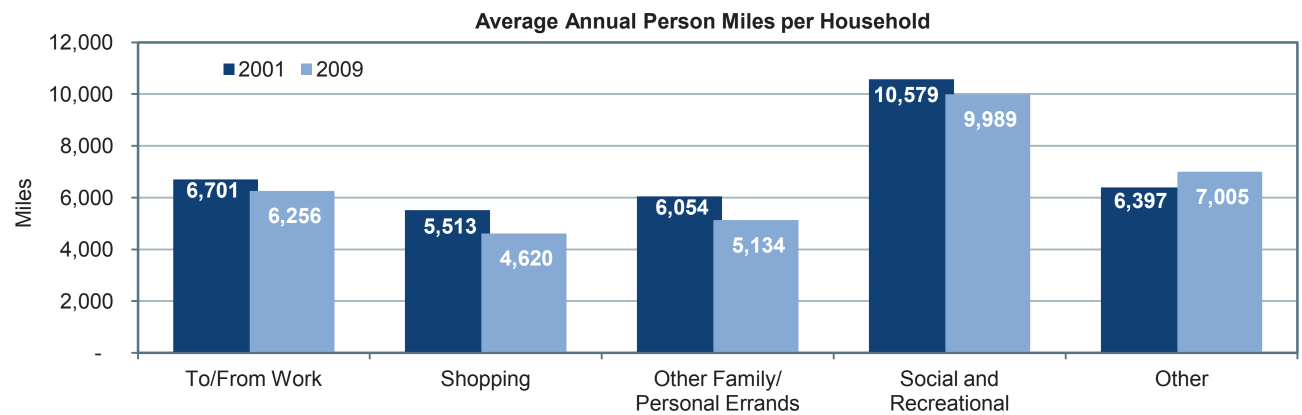
NHTS Non-Work Trip Purposes

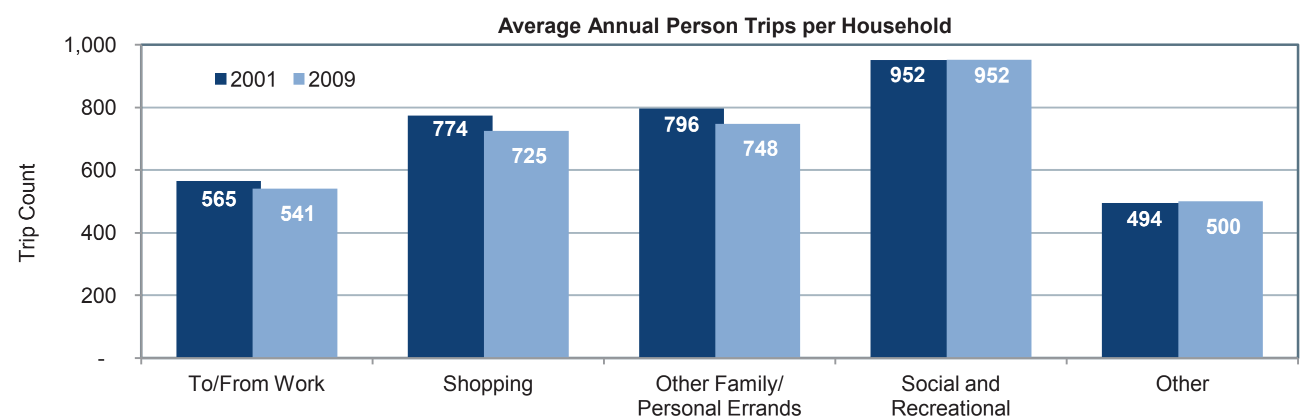
Social/recreational trips include activities such as going out for a meal; visiting friends or relatives; going to a movie or play; and exercising, playing sports, or going to the gym.

Two other significant purposes of travel are (1) shopping and (2) other family and personal errands, which includes purchase of services such as haircuts or dry cleaning, picking up or dropping off someone else, or other family or personal errands and obligations.

The 2009 data show that the declines in person miles and person trips were most notable in travel to and from work, personal and family errands, and social and recreational travel, while shopping and trips for other purposes were relatively constant. Travel to work shows a 10-percent decrease in miles and a 7-percent decrease in trips between 2001 and 2009. In 2009, American households were traveling 13.9 percent less for family or personal errands, and trip lengths for these family errands also dropped by 10 percent compared to 2001. In addition, daily person miles for social and recreational purposes declined by 9.5 percent between 2001 and 2009. (See *Exhibit 1-6*.) Two of the three purpose groupings—errands and social/recreational—are those for which most households have the greatest discretion in amount of travel. Further research of this behavior would be useful for policy considerations because family and personal errands and social and recreational travel have generally been the two most prevalent reasons for travel since 1990. This research would combine NHTS data with other

Exhibit 1-6 **Average Annual Person Miles and Person Trips per Household by Trip Purpose**





Note: The travel of children aged 0–4 is excluded from 2001 NHTS data to make it compatible with other years.

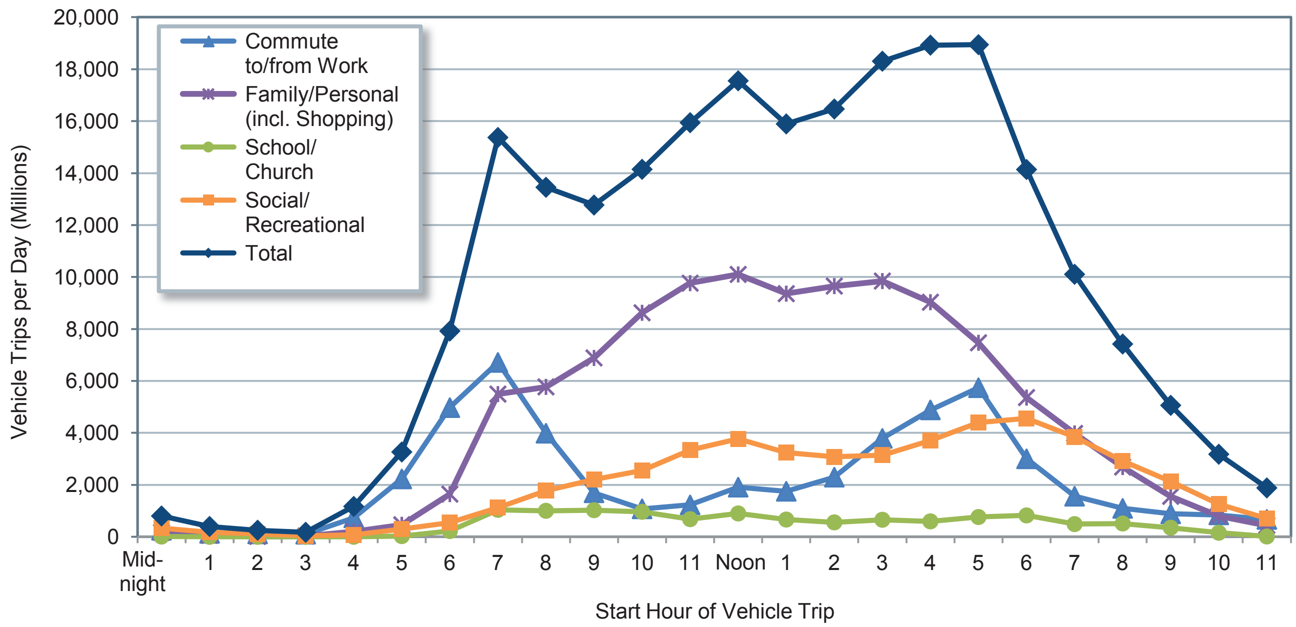
Source: 2001 and 2009 NHTS.

sources to determine the extent to which reduction in these trips between 2001 and 2009 was due to the economic environment at the time or to structural changes in how Americans view daily travel. The latter would have impact on transportation policy and priorities.

Travel by Time of Day

NHTS data allow for an examination of vehicle trips by purpose and time of day. Peak travel period information is salient to the study of congestion. *Exhibit 1-7* shows the morning and evening peak periods by vehicle trip purpose. Predictably, the traditional peaks of 6 to 9 in the morning and 4 to 7 in the evening reflect commuting to and from work. There is an additional minor peak in total vehicle trips around noon. According to the 2009 NHTS, 34.8 percent of workers have the option of flexible arrival times and about 11 percent of workers have the option of working from home some of the time. This increased flexibility is one of the factors that appears to be reflected in the pattern of travel by time of day. Most of these vehicle trips were for family and personal errands, which are more prevalent between noon and 3 p.m.

Exhibit 1-7 Number of Vehicle Trips by Start Time and Trip Purpose



Source: 2009 NHTS. See 2009 NHTS Summary of Travel Trends, Figure 12.

Usual and Actual Commute: A Typical Day Versus a Specific Day

The NHTS has questions designed to capture both the "usual" mode of travel to work in a traveler's previous work week and the "actual" mode of commuting on a specific Travel Day recorded in a travel diary. Comparing the usual mode to the actual travel day trip provides a measure in the day-to-day variability in commute modes, as well as a check on the tendency of respondents to give socially desirable responses. This comparison is particularly important because it gives context to the data on usual mode to work that is collected in the annual American Community Survey (ACS) that replaced the Decennial Census Long Form after 2000. The ACS data on commuting is widely used in State and metropolitan transportation planning, and inclusion of the NHTS comparison on usual versus actual mode helps put the ACS commute data in an appropriate context. This is important because the trip to work is central to the transportation planning process, particularly for the travel demand models used in developing metropolitan and statewide transportation plans.

The comparisons in *Exhibit 1-8* between usual and actual mode of travel show that 93 percent of workers who reported that that they usually drive alone did indeed drive alone on their assigned Travel Day. On the other hand, only about 80 percent of workers who said they usually walk to work actually walked on their assigned Travel Day. Carpoolers showed the greatest change in their comparison of usual to actual travel between 2001 and 2009; in 2001, 75 percent of workers who reported they usually carpooled did carpool on their travel day, but by 2009, only about 55 percent of those who reported that they usually carpooled actually did carpool, and 43 percent of those who reported that they usually carpooled actually drove alone. Finally, for those who said they usually took transit, about 68 percent actually did take transit on Travel Day, and when these individuals did change their mode, about 13 percent of these then switched to driving alone and another 9 percent carpooled.

Exhibit 1-8 Percentage Agreement Between Usual Mode to Work and Actual Commute Mode on Travel Day

Usual Commute Mode	Actual Commute Mode on Travel Day: Drove Alone	Carpool	Transit	Walk	Bike	Other
Drove Alone	93.5	5.6	0.1	0.5	0.1	0.4
Carpool	42.9	54.8	0.5	1.0	0	0.8
Transit	13.2	9.2	68.3	6.6	0.8	1.9
Walk	6.1	9.3	3.4	80.2	0.2	0.7
Bike	13.8	3.3	6.0	2.6	73	1.4
Other	64.1	19.0	4.2	4.3	0.3	8

Note: Based on workers who reported both a usual commute mode 'last week' and work trip mode on the assigned travel day.

Source: 2009 NHTS. See 2009 NHTS Summary of Travel Trends, Table 26.

Baby Boomer Travel Trends

By 2050, about one in four members of the U.S. population will be over the age of 65. The cohort of people age 65 and older is projected to grow by another 60 percent during the next 15 years or until 2035. Maintaining the mobility of this group of people 65 or older is a major issue both for the group and for their adult children, who often bear the responsibility for transporting their parents.

In 2009, people age 65 and older made about 45.5 billion trips, which represented an 11-percent increase in this cohort's total travel from 2001. This total travel encompassed all modes of travel including household private vehicles, transit, motorcycles, walking, and biking. However, travel per capita for this age group declined. For this aging group, the per-person measures of trips and miles decreased by about 6 percent and 12 percent, respectively, from 2001. *Exhibit 1-9* shows that, in 2009, women in this age range make 17 percent fewer daily trips and travel about one-third less than men in the same age range. The NHTS recorded 89 percent of older men as drivers, compared with only 73 percent of older women. This trend is expected to change as the percentage of women drivers

Exhibit 1-9 Average Daily Person Trips and Miles per Person

Age	Total 2001	Total 2009	Men 2001	Men 2009	Women 2001	Women 2009
Person Trips per Person						
Under 16	3.4	3.2	3.5	3.2	3.4	3.2
16 to 20	4.1	3.5	4	3.3	4.2	3.7
21 to 35	4.3	3.9	4.2	3.7	4.5	4.1
36 to 65	4.5	4.2	4.4	4.1	4.5	4.3
Over 65	3.4	3.2	3.8	3.5	3.1	2.9
Person Miles per Person						
Under 16	24.5	25.3	24.6	27.2	24.4	23.3
16 to 20	38.1	29.5	34.1	28.2	42.5	31
21 to 35	45.6	37.7	49.8	40.5	41.5	35
36 to 65	48.8	44	57.7	50.9	40.4	37
Over 65	27.5	24	32.9	30.5	23.5	19.3

Note: Travel for children aged 0-4 is excluded from 2001 NHTS data to make it comparable to 2009.

Source: 2001 and 2009 NHTS.

age 65 or older increases. Women who turn 65 today most likely grew up driving, and, as such, the percentage of women drivers 65 and older, while historically low, will become closer to that of older men. *Exhibit 1-10* shows the decrease in per capita baby boomer travel between 2001 and 2009. Note that this trend is consistent with those of other age cohorts.

Additional discussion of these travel trends can be found in Chapter 1 of the 2010 C&P Report, in the section titled "Aging of U.S. Population and Impact on Travel Demand."

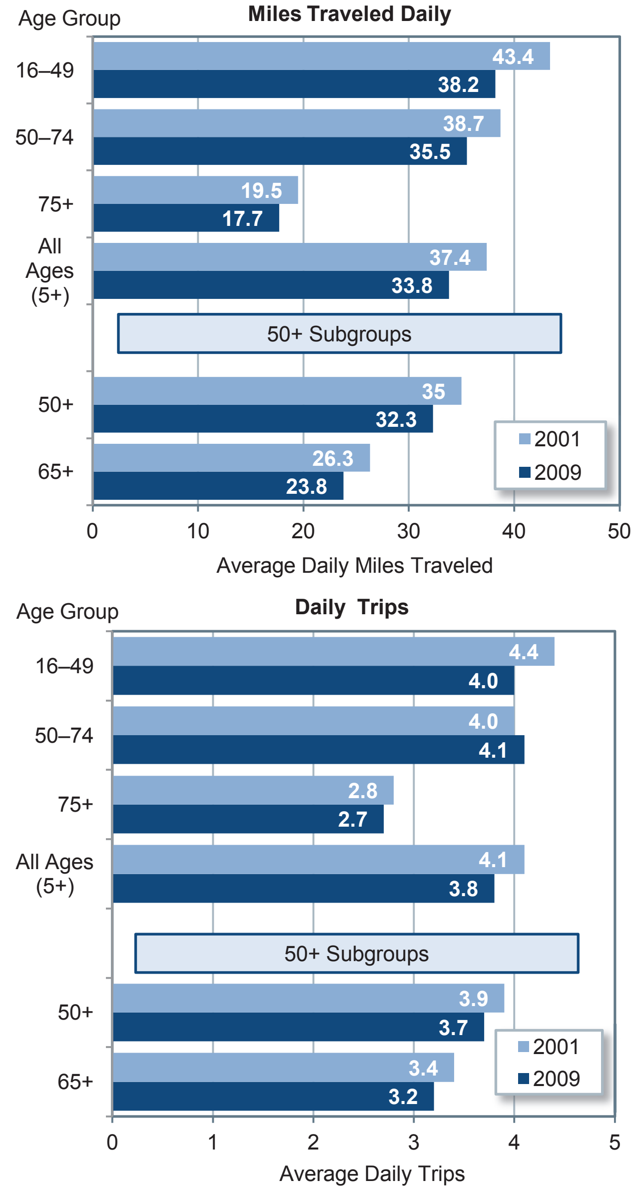
Travel of Millennials

Much attention has been given to changes in the travel behavior of the Millennial generation, generally defined as those born between 1982 and 2000. Compared with previous generations, youth travel has decreased. Youth are driving less, making fewer trips, and traveling shorter distances.

According to the National Household Travel Survey (NHTS) data, there are significant differences between current youth travel and the travel of youth in previous decades. Youth passenger miles traveled (PMT) on all modes of transportation in 2009 was 80 percent of PMT in 1995 and 2001. Similarly, vehicle miles of travel (VMT) in 2009 was only 75 percent of the VMT of youth in 1995 and 2001.

There is evidence to suggest that the travel choices of youth are being influenced by the constraints of their personal income. These choices may include foregoing vehicle ownership, driving less, and taking more public transit.

Exhibit 1-10 Average Daily Miles and Daily Trips per Person by Age



Source: 2001 and 2009 NHTS.

In addition, current national housing trends have shown that younger populations, although less settled than older populations, prefer to live in urban areas. As young people continue to gravitate towards urban areas, they will become accustomed to living in places that offer a variety of travel options.

Emerging Trends in Youth Travel: What Is Happening and Why?

High unemployment and personal income constraints due to the recession limit resources for travel.

Youth are still living at home with parents and sharing the family vehicle.

Increases in driver's licensing restrictions have resulted in more youth waiting longer to get their licenses.

Youth prefer to live in high-density areas where there are more modal options and shorter trip lengths.

Technology influences travel and how youth get their information.

Youth concerns for the environment play a role in their travel decisions.

Driver's licensing rates also show a drop between 1995 and 2009. In both 1995 and 2001, 86 percent of all 16-to-28-year-old males were licensed drivers; this drops to 80 percent in 2009. For 16-to-29-year-old females, the licensing rate stays stable at approximately 82 percent across all 3 survey years.

These are some of the emerging factors that are influencing the travel decisions of youth. Together, they warrant further discussion on emerging issues related to travel demand, transportation policy, and the needs and perspectives of those who are soon to be the most predominate users of the transportation system. These and other issues are the topic of research conducted by FHWA (Federal Highway Administration, Office of Transportation Policy Studies, The Next Generation of Travel: Final Report, 2013).

Aging of the Household Vehicle Fleet

Like the population as a whole, the household vehicle fleet is also aging. NHTS collects information about household vehicles, including make, model, model year, estimates of annual mileage, and which household member is the primary driver (see *Exhibit 1-11*). The basic pattern over time is a consistent decrease in household size matched with an increase in vehicles per household.

Exhibit 1-11 Household Size and Vehicles Owned over Time, 1969-2009 NHTS

	1969	1977	1983	1990	1995	2001	2009
Persons per household	3.16	2.83	2.69	2.56	2.63	2.58	2.50
Vehicles per household	1.16	1.59	1.68	1.77	1.78	1.87	1.86

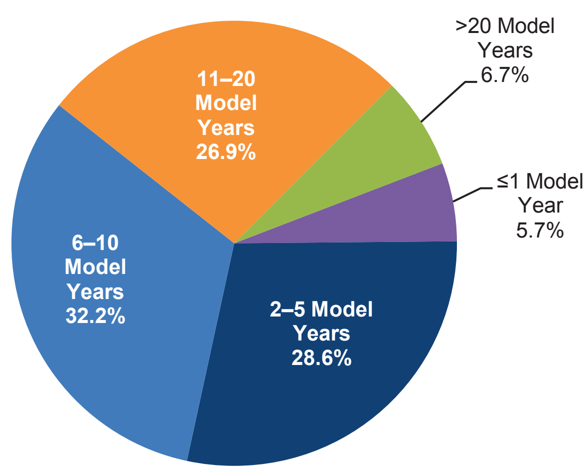
Note: The 1969 survey does not include pickups and other light trucks as household vehicles.

Source: NHTS data series. See 2009 NHTS Summary of Travel Trends, Table 2.

In 2009, there were about 211 million household vehicles or about 1.86 vehicles per household. Between 2001 and 2009, there was a 0.58-percent annual increase in the average number of household vehicles, in contrast to the long-term annual increase of 2.7 percent over the 40-year period between 1969 and 2009. This indicates that American households continue to depend heavily on automobiles, but appear to be reaching saturation in household vehicle ownership. On the other hand, the number of households with no vehicle available grew slightly by nearly 1 million households, representing a slight increase from 8.1 percent to 8.7 percent of all households. This may be due to changes in economic conditions or household location.

The aging of the household vehicle fleet continues to impact fuel consumption, air quality, and safety. Because over half the household vehicles on the road are more than 9 years old, recent automotive advances in energy efficiency, air quality, and safety are not fully realized in the national vehicle fleet. The 2009 NHTS reflects that the average age of a household vehicle increased from 8.87 years in 2001 to 9.38 years in 2009. In 2009, only 6 percent of household vehicles were 1 year old or newer, 32 percent of vehicles were between 2 and 5 years old, 34 percent were between 6 and 10 years old, and 7 percent were 20 years old or more (see *Exhibit 1-12*).

Exhibit 1-12 Age of Household Vehicles



Source: 2009 NHTS.

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Some Myths and Facts About Daily Travel

This section explores five common misperceptions about travel and what the actual data reveal about these issues.

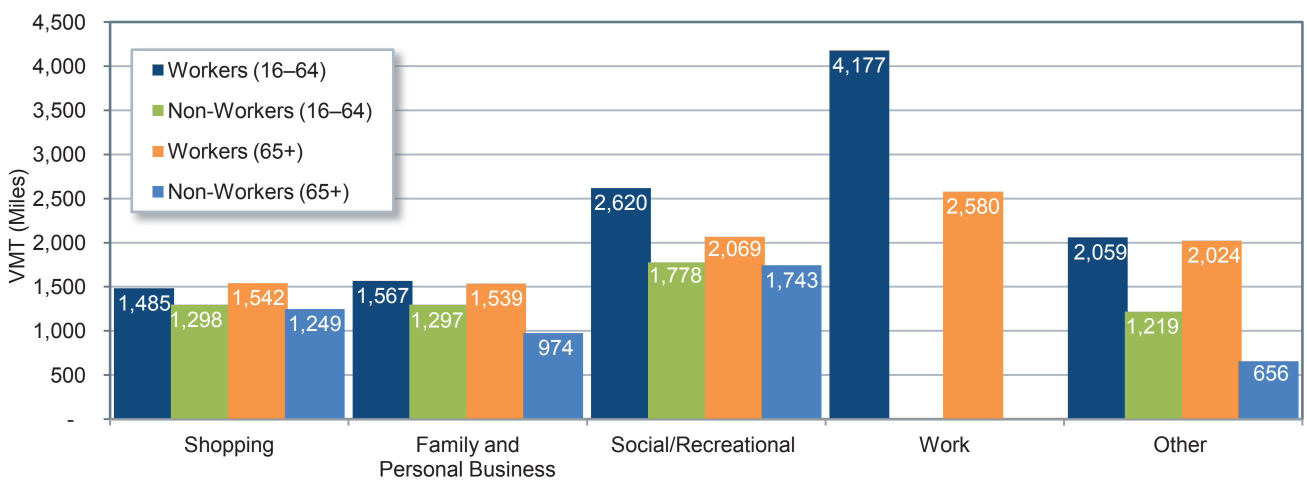
Myth 1: The majority of personal travel is for commuting to work.

Perhaps surprisingly, travel to and from the workplace accounts for only 16 percent of all person trips and 28 percent of all vehicle miles. Only 54 percent of the total population are workers, and 76 percent of the population generally regarded as working age (age 16 to 64) are employed. Even in times of lower unemployment, this percentage does not increase significantly.

Workers drive much more than their nonworker counterparts. Workers age 16 to 64 drive an average of 11,908 miles annually for all purposes, compared to 5,592 for those of the same age who are not employed. Of those 65 and older, those with jobs drive 9,754 miles annually, compared with 4,622 annual miles for those without jobs. The variation in miles driven by employment status is striking considering that workers typically drive more than twice the miles of their nonworking counterparts. Although some of this additional driving is to commute or for work-related travel, workers drive more than nonworkers for each major trip purpose group, as shown below. *Exhibit 1-13* displays trip purpose for four groups—workers 16 to 64, workers 65 or older, nonworkers 16 to 64, and nonworkers 65 or older. For workers, 35 percent of driving is for commutes to work, followed by 22 percent for social/recreational trips, and 13 percent each for family/personal errands and for shopping. Together, these four purposes account for 83 percent of driving done by workers.

For the miles driven by the 46 percent of Americans who are not workers, social/recreational travel (34 percent of their VMT) is followed by shopping (24 percent) and family and personal business (23 percent), for a total of 81 percent of their driving.

Exhibit 1-13 **Annual VMT per Person by Trip Purpose, Age, and Worker Status**



Source: 2009 NHTS.

Myth 2: Americans love their cars, and that's why they don't walk or take transit.

Americans' often cited "love affair" with their cars may have much more to do with the design of our neighborhoods and land use decisions than with transportation. Higher-density areas can provide more opportunities for walking, biking, and transit use than low-density areas. In some low-density neighborhoods, transit services are not cost-effective to provide and there are few destinations, such as schools, jobs, or shopping, within walking distance. People may be left with no other choice but to drive.

Exhibit 1-14 visually portrays the relationship between population density and the use of transit, walking, and private vehicles.

Households living in higher-density areas have more transportation choices. Of the 50 Metropolitan Statistical Areas (MSAs) with populations greater than 1 million, 14 have at least 10 percent of their populations living in high-density block groups of 10,000 or more persons per square mile. Excluding New York, which accounts for such a huge share of the Nation's transit trip-making, residents of these 14 areas are at least 8 times more likely to make a trip on transit than those who live in MSAs of 1 million or less, and

14 MSAs With at Least 10 Percent of People Living in High Density Block Groups of 10,000 Persons or More per Square Mile

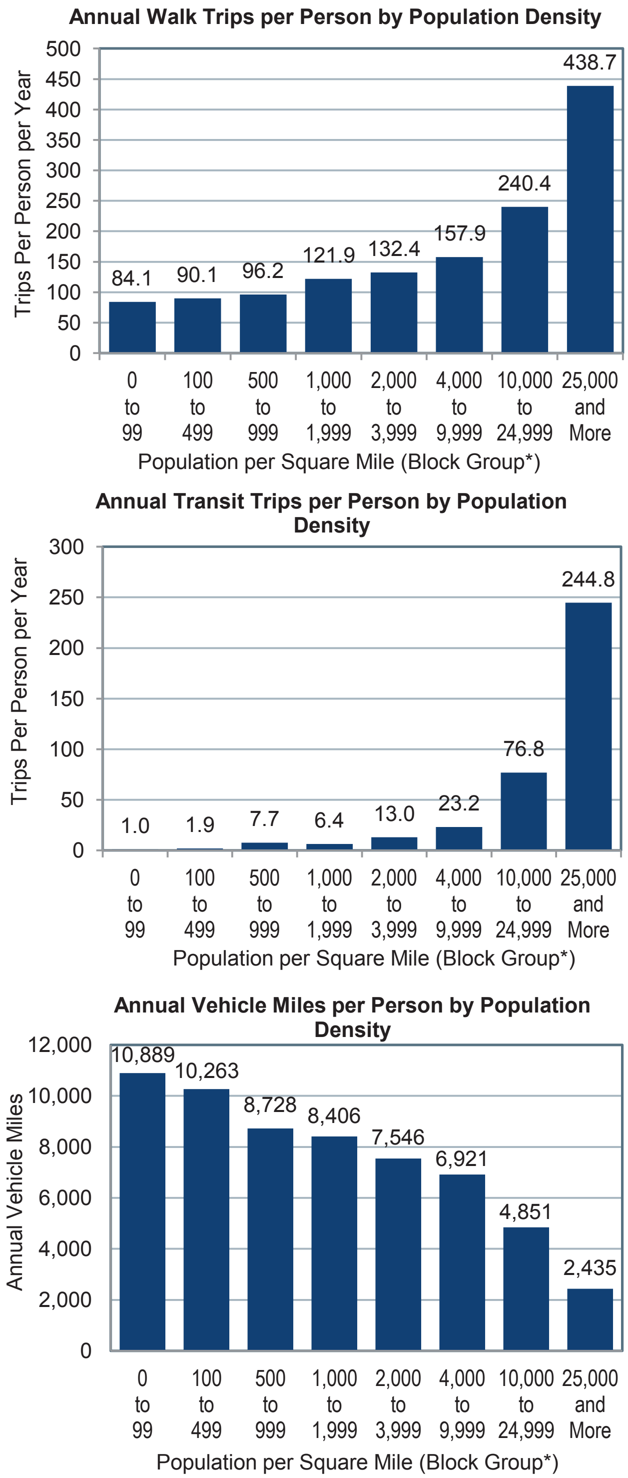
New York – 48.0%	Miami – 23.1%
Los Angeles – 43.2%	Las Vegas – 22.2%
San Francisco – 33.7%	Washington DC – 15.7%
Chicago – 33.0%	Providence – 14.4%
Philadelphia – 27.7%	Milwaukee – 12.2%
San Diego – 26.8%	Pittsburgh – 11.4%
Boston – 24.1%	Sacramento – 10.4%

more than 50 times more likely to use transit than those living outside an MSA. Residents of a Big 14 area make walking trips at twice the rate of those in MSAs of 1 million or less, and 2.8 times more than those living outside an MSA (see *Exhibit 1-15*). (See the discussion of livable communities in Chapter 5 of this edition of the C&P report).

Myth 3: Households without vehicles rely completely on transit, walk, and bike.

Although zero-vehicle households rely more heavily on transit, walk, and bike modes than vehicle-owning households do, people in zero-vehicle households accomplish a majority of their travel in private vehicles owned by others. Approximately 9.8 million households, or 8.6 percent of all U.S. households, do not own a vehicle. People in zero-vehicle households average about 100 minutes of travel a day, 76 percent of which are as a driver or passenger in a private vehicle; they accomplish 50.7 percent of their person miles of travel in private vehicles.

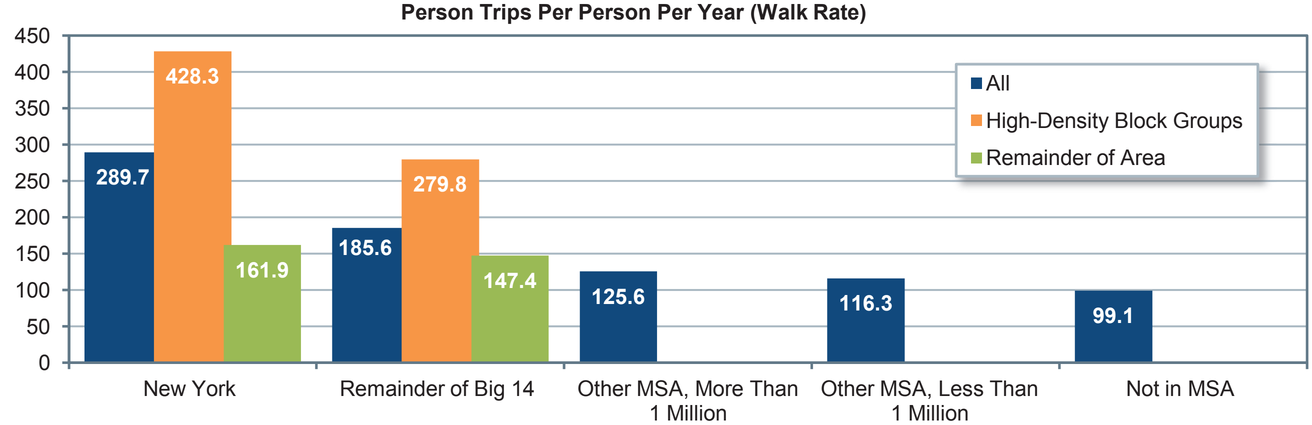
Exhibit 1-14 Impact of Population Density on Transportation Mode

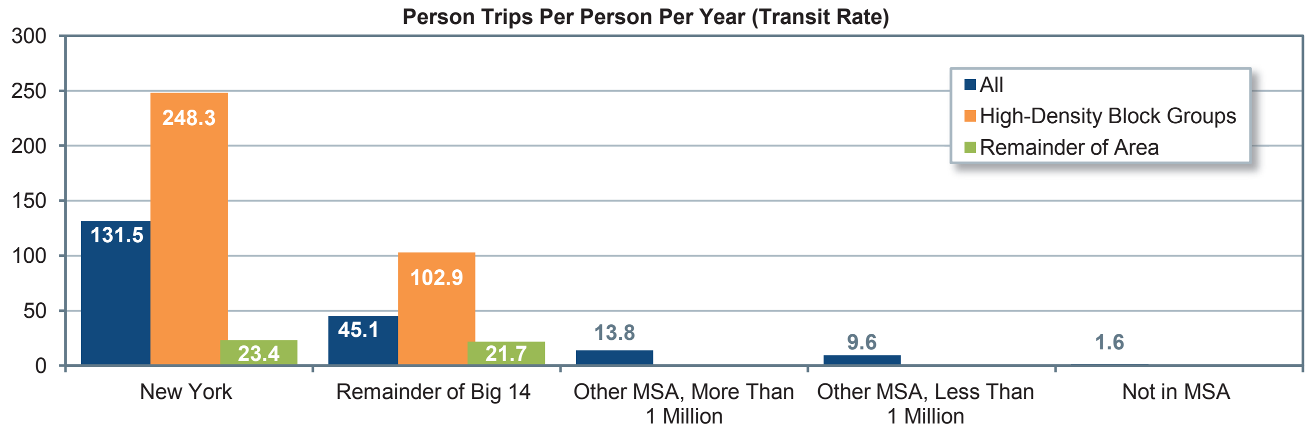


*Block group – a standard Census Bureau term indicating a subgroup of a Census Tract composed of approximately 1,500 people but may vary from 600-3,000 people.

Source: 2009 NHTS. Population density data was appended to the NHTS files from the Nielsen-Claritas annual demographic update. See www.claritas.com/MarketPlace/Default.jsp.

Exhibit 1-15 Walk and Transit Rates by Area Type

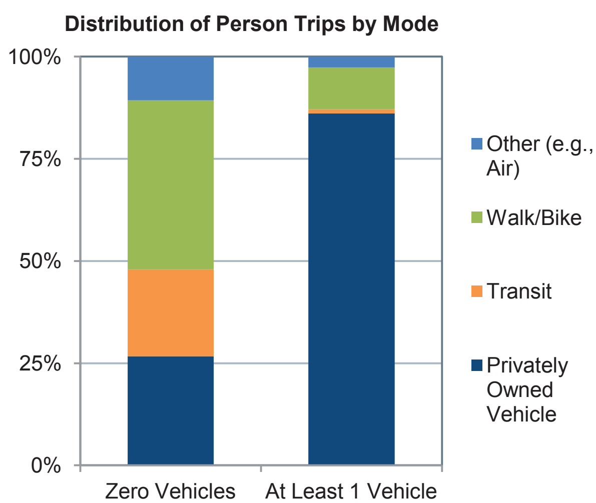


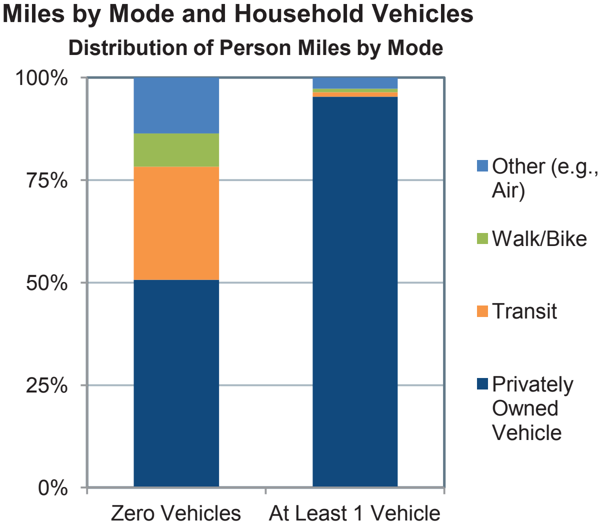


Source: 2009 NHTS. Population density data was appended to the NHTS files from the Nielsen-Claritas annual demographic update.

Because the data in this section are presented as person trips and person miles, private vehicle travel includes travel in a vehicle as a driver and as a passenger. Those in zero-vehicle households could be using a car borrowed from a friend or relative or be a vehicle passenger in another household's car. (See *Exhibit 1-16*.) The vehicle occupancy per private vehicle trip by members of zero-vehicle households is, as expected, consistently larger (2.06) than the occupancy rate of vehicle-owning household members (1.67).

Exhibit 1-16 Distribution of Person Trips and Person Miles by Mode and Household Vehicles





Source: 2009 NHTS.

Whether the household is without a vehicle by necessity or by choice, its daily travel is considerably lower than that of vehicle-owning households. While a zero-vehicle household has half the daily person trip rate of a vehicle-owning household, their daily person miles of travel is one-fifth that of their vehicle-owning counterparts.

Car Share Services

Some of households that are non-vehicle owning by choice are using the expanding option of car-share services, such as Zip Cars and Car2go. Unlike traditional car rental agencies, car-sharing is set up to allow rentals by the minute or the hour. These services are designed for high-density areas and often have reserved parking spaces, an especially convenient benefit for urban dwellers. The NHTS did not collect data on car-sharing in the 2009 survey, but may do so in 2015.

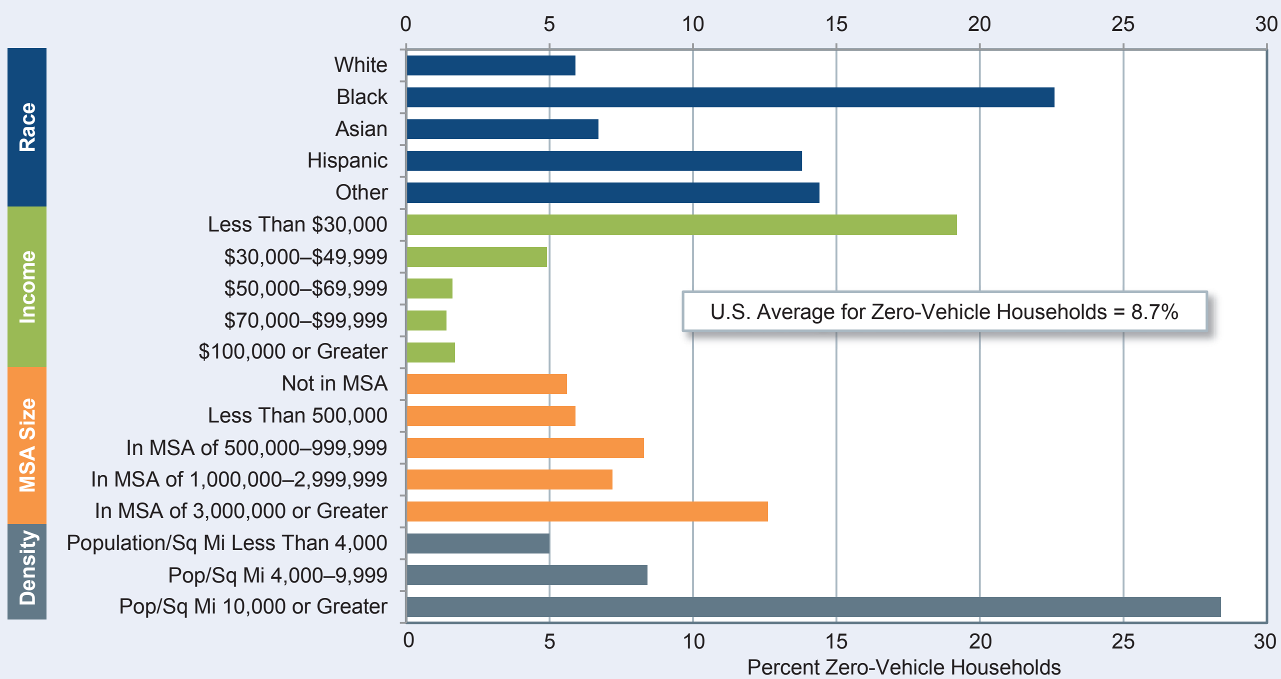
Who are the zero-vehicle households?

Q&A

Exhibit 1-17 summarizes the characteristics of zero-vehicle households. Some observations:

- They are disproportionally Black and Hispanic. The share of all U.S. households without a vehicle is 8.7 percent; this percentage goes up to 13.8 percent for Hispanic households and 22.6 percent for Black households.
- They are smaller than average households and have lower incomes. Of all zero-vehicle households, 70 percent have incomes less than $30,000.
- They are typically poorer than average households, but not in all cases. Sixty percent of zero-vehicle households make less than $20,000 annually, as compared to 16 percent of vehicle-owning households.
- Of zero-vehicle U.S. households, 4.3 percent earn more than $80,000 a year, and the majority of this group lives in the New York Metro Region.
- Whether at the low or high end of the income scale, zero-vehicle households tend to be in the largest metro areas with populations of 3 million or more. Zero-vehicle households make up 8.7 percent of all U.S. households, but they make up 12.6 percent of the households in these largest metro areas. In other words, 51 percent of all zero-vehicle households live in areas of 3 million or more, compared to 35 percent for households with one or more vehicles.

Exhibit 1-17 Characteristics of Zero-Vehicle Households



Source: 2009 NHTS.

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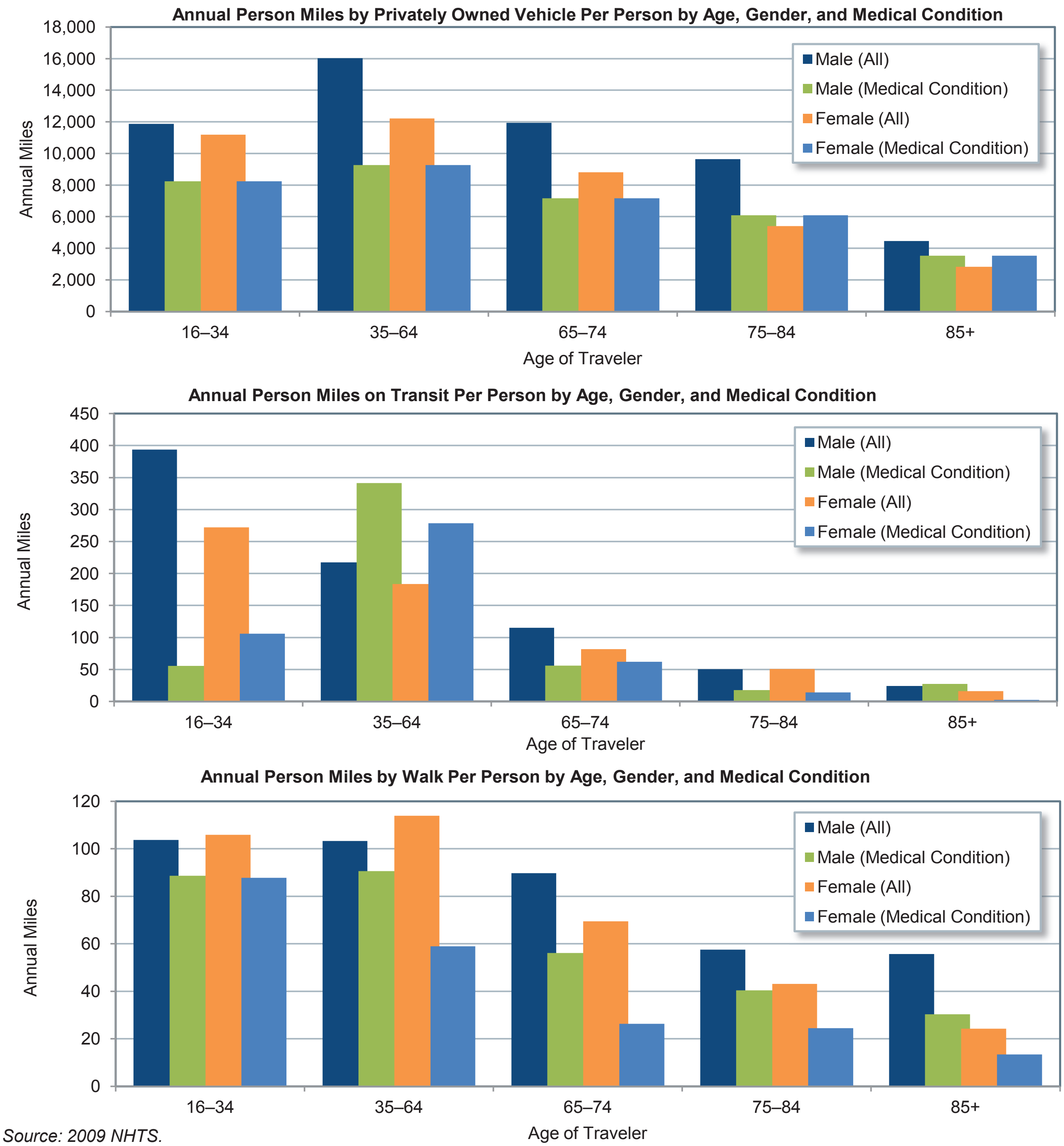
Myth 4: When elderly drivers give up their driver's license they maintain mobility by using transit or walking instead of using private vehicles.

Like the rest of the U.S. population, the elderly are heavily dependent on private vehicle travel to meet their needs. Although some relocate, a large portion of the elderly age in place in the homes where they raised their families. Issues of diminished eyesight, response time, and physical mobility that might keep an older person from driving may also keep them from being able to walk or take transit, making them more likely to travel as a private vehicle passenger or simply stay at home.

The NHTS collects data on whether or not respondents have medical conditions that make it difficult for them to travel outside the home. As shown in *Exhibit 1-18*, those with a travel disability have a lower rate of

Exhibit 1-18 **Person Miles by Private Vehicle, Transit, and Walk by Age and Travel Disability**



Source: 2009 NHTS.

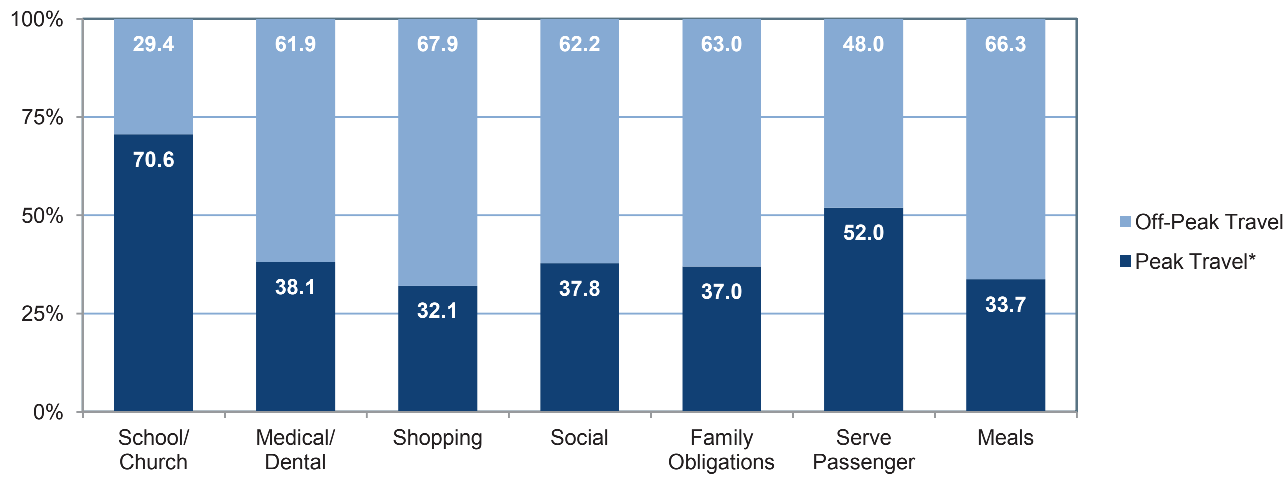
transit use and walking than others of the same age and there is a slight increase in the relative use of private vehicles, particularly by older women.

Myth 5: We can solve congestion by having people shift noncommuting trips outside of peak periods.

Encouraging the traveling public to make noncommuting trips outside of peak periods would appear to be a reasonable proposal for addressing congestion, but there are many scenarios that simply do not allow for such time flexibility. For example, picking up your child from an athletic practice or an after-school event typically needs to be done when the child is ready, not some arbitrary time after peak period. A doctor's office would usually be open in morning and afternoon peak periods, but it would not likely be open in the evening. Although trips and travel for shopping and errand-running are not as constrained by time of day as some of the other trip purposes, many people choose to make these trips on their way to or from work.

While time-shifting may be possible for some share of trips, it is clear that the public is willing to put up with the inconvenience of congestion during peak periods to accomplish many of their travel needs. Exhibit 1-19 identifies the share of person trips in the peak period for different types of non-commuting trips.

Exhibit 1-19 **Percent of Person Trips by Selected Purpose During Peak and Off-Peak Hours**



* Peak period is defined as 6:30 a.m.–9:30 a.m. and 3:30 p.m.–6:30 p.m.

Source: 2009 NHTS.

Gas Prices and the Public's Opinions

The price of gas rose to a nationwide average of over $3.50 per gallon in May of 2008 and did not drop below that level until October of that year. It peaked at $4.11 per gallon in June and July.

In comparing the two survey years, 2001 and 2009, average daily vehicle miles by month remained around the same through August across the 2 years possibly because the public has come to expect some increases in gas cost during the summer travel season. (See *Exhibit 1-20.*) In August of 2001, gas prices declined and more daily driving occurred. This follows a typical pattern of personal VMT peaking in August. However, this pattern did not repeat itself in 2008, when gas prices remained high for about 4 months and people adjusted their average daily miles. The average daily VMT per driver decreased by 13 percent in August of 2008, when gas prices remained higher than $3.80 per gallon. This apparent delayed response to high gas prices may have been because the public was waiting to see how long the phenomenon would continue. According to the NHTS data, it appears that most people decided to cut their driving in August of 2008 by an average of 3 to 4 daily miles relative to August 2001.

Exhibit 1-20 Average Gas Price per Month and Daily VMT per Driver, 2001–2002 and 2008–2009

	Avg. Gas Price (in 2008 $)	Daily VMT per Person	Avg. Gas Price (in 2008 $)	Daily VMT per Person
	2001		2008	
March	$1.77	16.6	$3.29	20.4
April	$1.94	22.3	$3.51	23.1
May	$2.12	22.7	$3.82	22.2
June	$2.02	23.4	$4.11	22.0
July	$1.79	22.9	$4.11	22.6
August	$1.78	24.0	$3.83	20.8
September	$1.90	21.8	$3.76	21.2
October	$1.66	21.9	$3.11	22.8
November	$1.48	22.3	$2.21	21.6
December	$1.37	21.3	$1.75	21.1
	2002		2009	
January	$1.40	21.0	$1.84	19.9
February	$1.41	23.7	$1.98	22.2
March	$1.57	22.7	$2.01	22.0
April	$1.76	21.6	$2.10	21.7

Source: 2009 NHTS for VMT per Driver. Average Gas Price is from the Energy Information Administration (EIA), Forms EIA-782A, "Refiners'/GasPlant Operators' Monthly Petroleum Product Sales Report," and EIA-782B, "Resellers'/Retailers' Monthly Petroleum Product Sales Report."

Number One Issue for the Public: Price of Travel

Questions to elicit the public's opinions about transportation were included in the 2009 NHTS because understanding their attitudes and perceptions is valuable when prioritizing policy. Respondents were asked to select what they considered the most important issue from a list of six pre-identified issues:

- Highway congestion
- Access to and availability of public transit
- Lack of walkways and sidewalks
- Price of travel including things like transit fees, tolls and the cost of gasoline
- Aggressive and distracted drivers
- Safety concerns.

One-third of all respondents selected the price of travel as the most important issue. When drivers were divided by demographic categories such as gender, race, income, and education, the data revealed no significant difference in their selection of travel price as the primary issue. A disproportionate share of respondents say that price of travel was their number one concern. This may have been due to the rising cost of gasoline or because of the economic recession during the data collection period.

Households with incomes of $40,000 to $70,000 ranked price as most important issue about 5 percent more often than households in both higher and lower income categories. During the post-peak period between October 2008 and April 2009, almost all households at all levels started shifting their opinions to the issues of safety and aggressive drivers (approximately 20 percent each) but 27 percent kept price as their major issue. Only households in the highest income bracket (those with incomes of $100,000 or more) selected congestion as their most important concern in this post-peak period (about 26 percent). This suggests that the gas price fluctuation remained important with middle income households throughout the study more so than with other households.

Freight Movement

The economy of the United States depends on freight transportation to link businesses with suppliers and markets throughout the Nation and the world. Freight impacts nearly every American business and household in some way. American farms and mines rely on affordable and reliable transportation to compete against their counterparts around the world. Domestic manufacturers rely on remote sources of raw materials to produce goods. Wholesalers and retailers depend on fast and reliable transportation to obtain inexpensive or specialized goods. In the expanding world of e-commerce, households and small businesses increasingly depend on freight transportation to deliver purchases directly to them. Service providers, public utilities, construction companies, and government agencies rely on freight transportation to obtain needed equipment and supplies from distant sources.

The U.S. economy requires effective freight transportation that operates at minimum cost and allows shippers and freight carriers to quickly respond to the demands for goods. As the economy grows over the next several decades, the demand for goods and the volume of freight transportation activity will only increase. Current volumes of freight are straining the capacity of the transportation system to deliver goods quickly, reliably, and cheaply. Anticipated growth of freight could overwhelm the system's ability to meet the needs of the American economy unless public agencies and private industry work together to improve the system's performance.

Freight Transportation System

The FHWA's Freight Facts and Figures 2011 publication shows that the U.S. freight transportation system moves nearly 52 million tons of freight worth more than $46 billion each day to meet the logistical needs of the Nation's 117 million households, 7.4 million business establishments, and 89,500 government units. This system includes nearly 11 million single-unit and combination trucks, nearly 1.4 million locomotives and rail cars, and more than 40,000 marine vessels. The system operates on more than 450,000 miles of arterial highways, nearly 140,000 miles of railroads, 11,000 miles of inland waterways and the Great Lakes-St. Lawrence Seaway system, and 1.7 million miles of petroleum and natural gas pipelines. The U.S. Army Corps of Engineers' Waterborne Commerce of the United States 2007 publication identifies 146 ports that handle more than 1 million tons of freight per year.

The freight transportation system is more than equipment and facilities. As reported in Freight Facts and Figures 2011, freight transportation establishments with payrolls primarily serving for-hire transportation and warehousing employ nearly 4.2 million workers. Truck transportation businesses make up the largest freight transportation employment sector in the U.S., employing more than 2.6 million workers in 2010. Other freight transportation occupations included rail and water vehicle operators, as well as other occupations such as warehousing and storage, equipment manufacturing, equipment maintenance, and other transportation support service providers.

Freight Transportation Demand

Freight movements in the United States take a variety of forms, from the shipment of farm products across town to the shipment of electronic devices across the world. These goods move within, to, and from the U.S. via the Nation's highways, railroads, waterways, airplanes, and pipelines, sometimes using a combination of modes to complete the trip. Due to the country's well-developed highway network and the transport

connectivity and flexibility that this network provides, the majority of freight moved within, to, or from the United States is transported by truck. *Exhibit 1-21* shows a breakdown of freight movements by mode, measured by both tonnage and value of shipment.

Exhibit 1-22 shows a map illustrating the distribution of the tonnage information shown in the table in *Exhibit 1-21* for truck, rail, and inland water shipments on the United States freight transportation network.

Exhibit 1-23 shows the same information as *Exhibit 1-22*, but only includes long-haul truck shipments on the National Highway System.

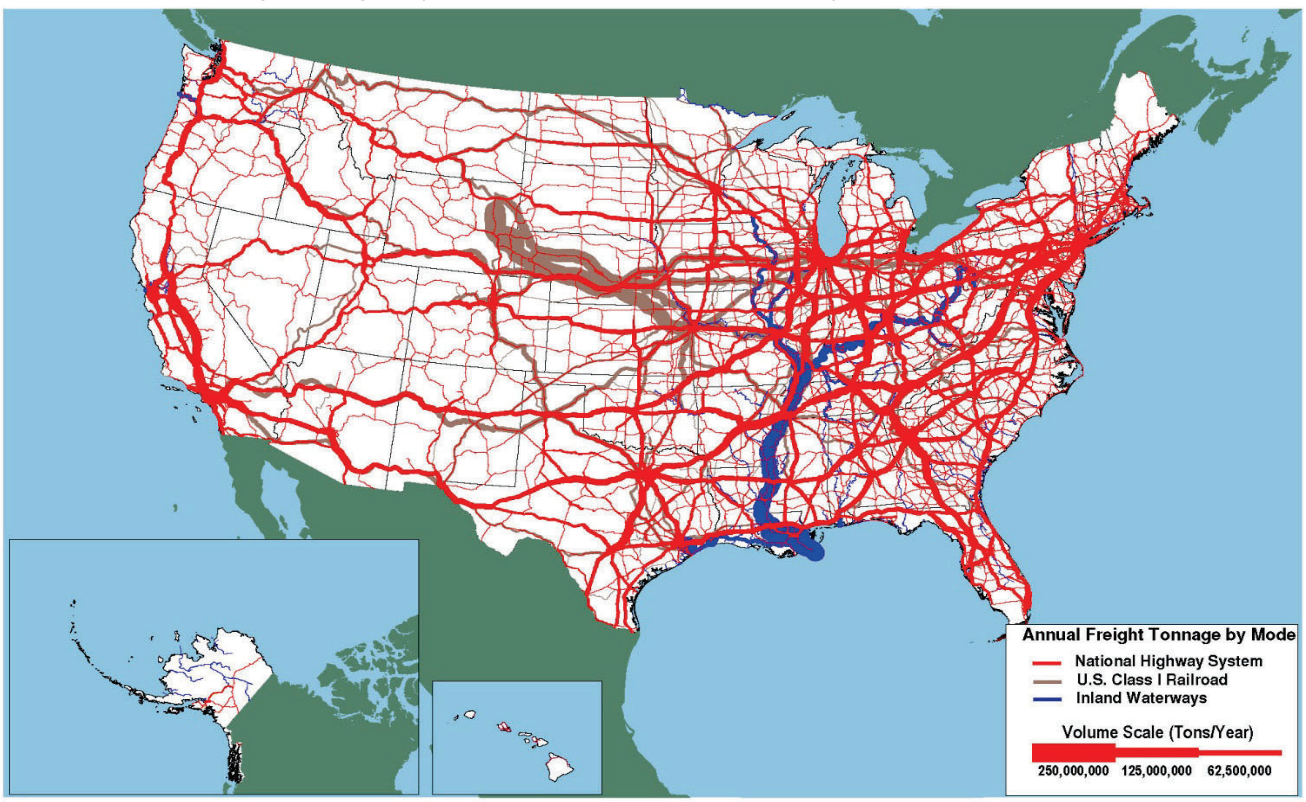
Exhibit 1-21 Goods Movement by Mode, 2007

Mode	Tons (Millions)	Percent	Value (Billions of Dollars)	Percent
Truck	12,778	67.7%	10,780	64.7%
Rail	1,900	10.1%	512	3.1%
Water	941	5.0%	339	2.0%
Air, Air & Truck	13	<0.1%	1,077	6.5%
Multiple Modes & Mail	1,424	7.5%	2,879	17.3%
Pipeline	1,507	8.0%	723	4.3%
Other & Unknown	316	1.7%	341	2.0%
Total	**18,879**	**100%**	**16,651**	**100%**

Notes: Numbers may not add to totals due to rounding. All truck, rail, water, and pipeline movements that involve more than one mode, including exports and imports that change mode at international gateways, are included in multiple modes and mail to avoid double counting. As a consequence, rail and water totals in this table are less than other published sources. By contrast, all air cargo movements that are shipped via truck at the ends of the trips are included in the "Air, Air & Truck" category. In addition, it should be noted that raw tonnage statistics does not take into account the distance these goods were moved. To use one example, a shipment, such as a shipping container, that is transported 2 miles by truck and 2,000 miles by rail is treated the same when measured by tonnage.

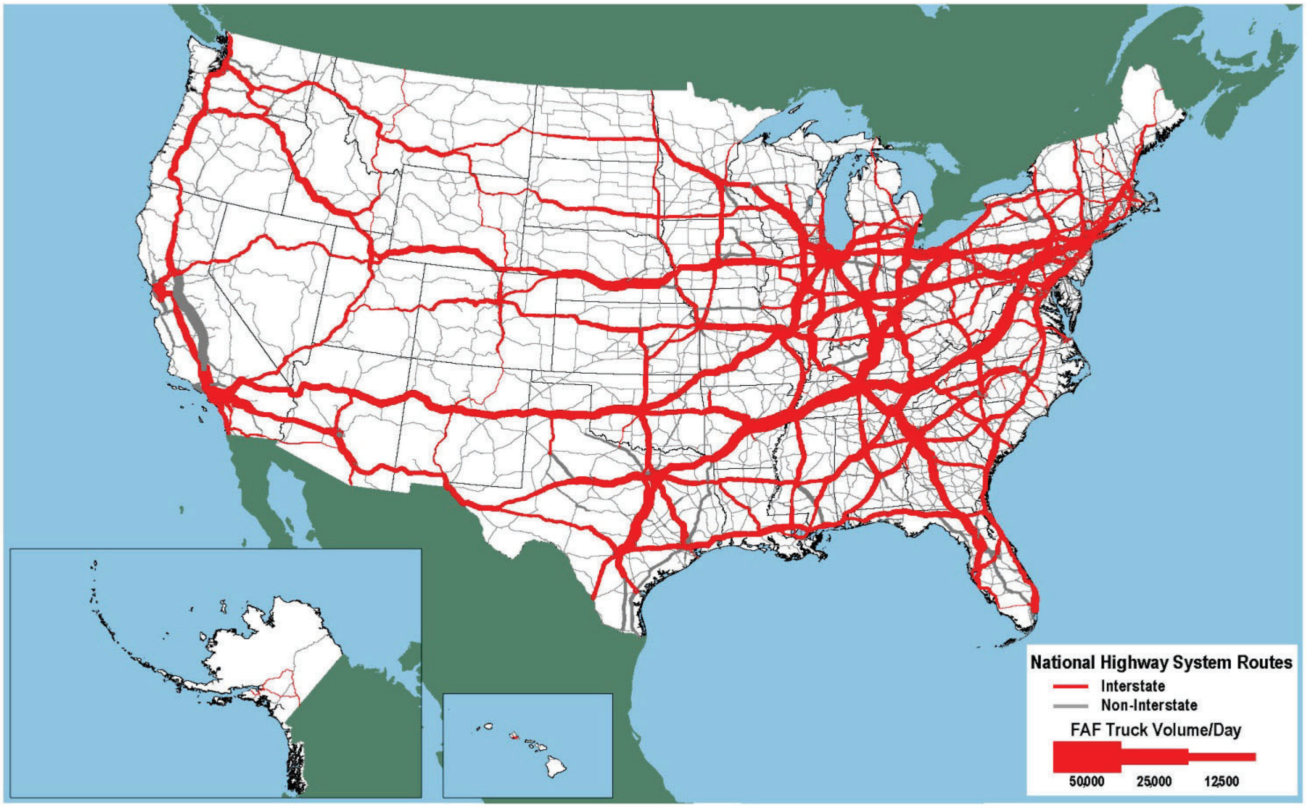
Source: Freight Analysis Framework 3.3.

Exhibit 1-22 Tonnage on Highways, Railroads, and Inland Waterways, 2007



Sources: Highways —*U.S. Department of Transportation, Federal Highway Administration, Freight Analysis Framework, Version 3.2, 2010.* Rail—Based on *Surface Transportation Board, Annual Carload Waybill Sample* and rail freight flow assignments done by Oak Ridge National Laboratory. Inland Waterways—*U.S. Army Corps of Engineers (USACE), Annual Vessel Operating Activity and Lock Performance Monitoring System data*, as processed for USACE by the Tennessee Valley Authority, and *USACE, Institute for Water Resources, Waterborne Foreign Trade Data*. Water flow assignments done by Oak Ridge National Laboratory.

Exhibit 1-23 Average Daily Long-Haul Freight Truck Traffic on the National Highway System, 2007



Note: Long-haul trucks typically serve locations at least 50 miles apart, excluding trucks that are used in movements by multiple modes and mail.
Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, Version 3.1, 2010.

Freight Statistics

Many of the freight statistics in this section are derived from the Freight Analysis Framework (FAF) version 3 (FAF3) and FAF version 2 (FAF2). Both versions of the FAF include all freight flows to, from, and within the United States. FAF estimates are recalibrated every 5 years, primarily with data from the Commodity Flow Survey (CFS), and are updated annually with provisional estimates. The CFS, conducted every 5 years by the Census Bureau and U.S. DOT's Bureau of Transportation Statistics, measures approximately two-thirds of the tonnage covered by the FAF. FAF3 incorporates data from the 2007 CFS; FAF2 was based on 2002 data.

Statistics on trucking activity are primarily from FHWA's Highway Performance Monitoring System and the Census Bureau's Vehicle Inventory and Use Survey (VIUS). The VIUS links truck size and weight, miles traveled, energy consumed, economic activity served, commodities carried, and other characteristics of significant public interest, but was discontinued after 2002. For more information, see www.ops.fhwa.dot.gov/freight/freight_analysis/faf.

Freight movements are expected to increase over the next few decades as both the U.S. and global population grow and national and global consumer spending power increases, helping to increase demand for many types of goods. All freight transportation modes are expected to experience increased volumes, although the amount of expected growth will vary from mode to mode, as shown in *Exhibit 1-24*.

Even though the annual volume increases are modest for all modes, the cumulative 30-year growth for each mode is significant, and the increased volume will create additional strain on the entire freight transportation network, most notably the highway network. *Exhibit 1-25* shows a map containing the 2040 truck tonnage information shown in *Exhibit 1-24* plotted to the National Highway System.

Many key truck routes on the National Highway System are expected to experience significant increases in truck volume between 2007 and 2040. These projected traffic increases would have major implications for highway congestion and freight movement efficiency, especially near large urban areas along or near major truck corridors.

Exhibit 1-24 Weight of Shipments by Transportation Mode (Millions of Tons)

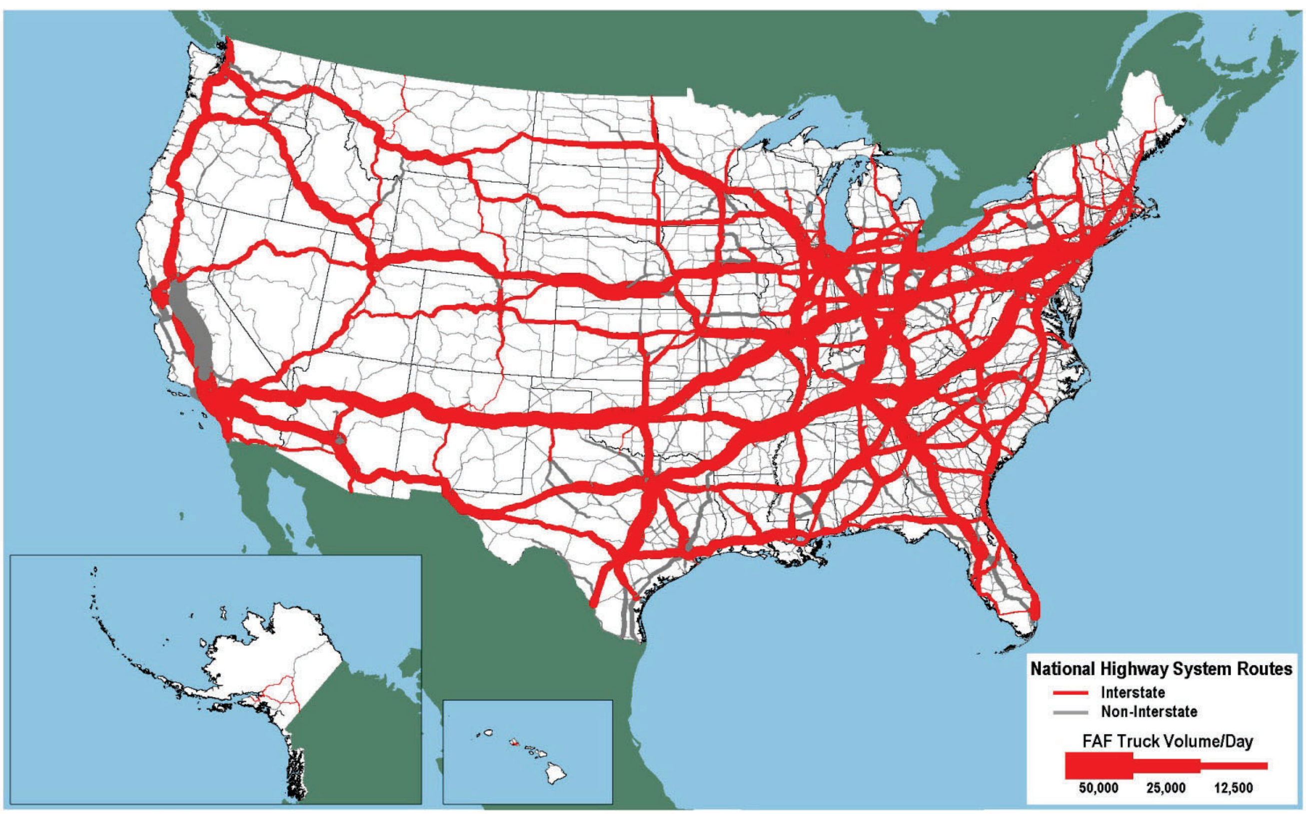
Mode	2007	2010	2040 Projected	Compound Annual Growth, 2010–2040
Truck	12,778	12,490	18,503	1.3%
Rail	1,900	1,776	2,353	0.9%
Water	941	860	1,263	1.3%
Air, Air & Truck	13	12	43	4.4%
Multiple Modes & Mail*	1,424	1,380	2,991	2.6%
Pipeline	1,507	1,494	1,818	0.7%
Other & Unknown	316	302	514	1.8%
Total	**18,879**	**18,313**	**27,484**	**1.4%**

** In this table, Multiple Modes & Mail includes export and import shipments that move domestically by a different mode than the mode used between the port and foreign location.*

Note: Data do not include imports and exports that pass through the United States from a foreign origin to a foreign destination by any mode. Numbers may not add to total due to rounding.

Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, version 3.2, 2011.

Exhibit 1-25 Average Daily Long-Haul Freight Truck Traffic on the National Highway System, 2040



Note: Long-haul trucks typically serve locations at least 50 miles apart, excluding trucks that are used in movements by multiple modes and mail.

Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, Version 3.1, 2010.

The differing volume and growth characteristics of the various freight transportation modes is related in large part to each mode's operating characteristics. These characteristics play a major role in determining how certain types of goods are transported. The routes, facilities, volumes, and service demands differ between higher-value, time-sensitive goods moving at high velocities and lower-value, cost-sensitive goods moving in bulk shipments, as shown in *Exhibit 1-26*.

Though trucking typically is considered a faster mode and handles a very high volume of high-value, time-sensitive goods, it also handles a significant share of lower-value bulk tonnage. This share includes movement of agricultural products from farms, local distribution of gasoline, and pickup of municipal solid waste. The haul length is typically very short and is intraregional in nature.

Truck movements are a significant component of overall highway traffic. Three-fourths of VMT by trucks larger than pickups and vans involves carrying freight, which encompasses a wide variety of products ranging from electronics to sand and gravel. Much of the rest of the large truck VMT is comprised of empty backhauls of truck trailers or shipping containers. Single-unit and combination trucks accounted for every fourth vehicle on almost 28,000 miles of the NHS in 2007, and 6,000 of those miles carried more than 8,500 trucks on an average day. The map shown in *Exhibit 1-27* identifies those major truck routes on the National Highway System, showing the routes that handle over 8,500 trucks per day and/or experience daily traffic that is composed of at least 25 percent truck traffic.

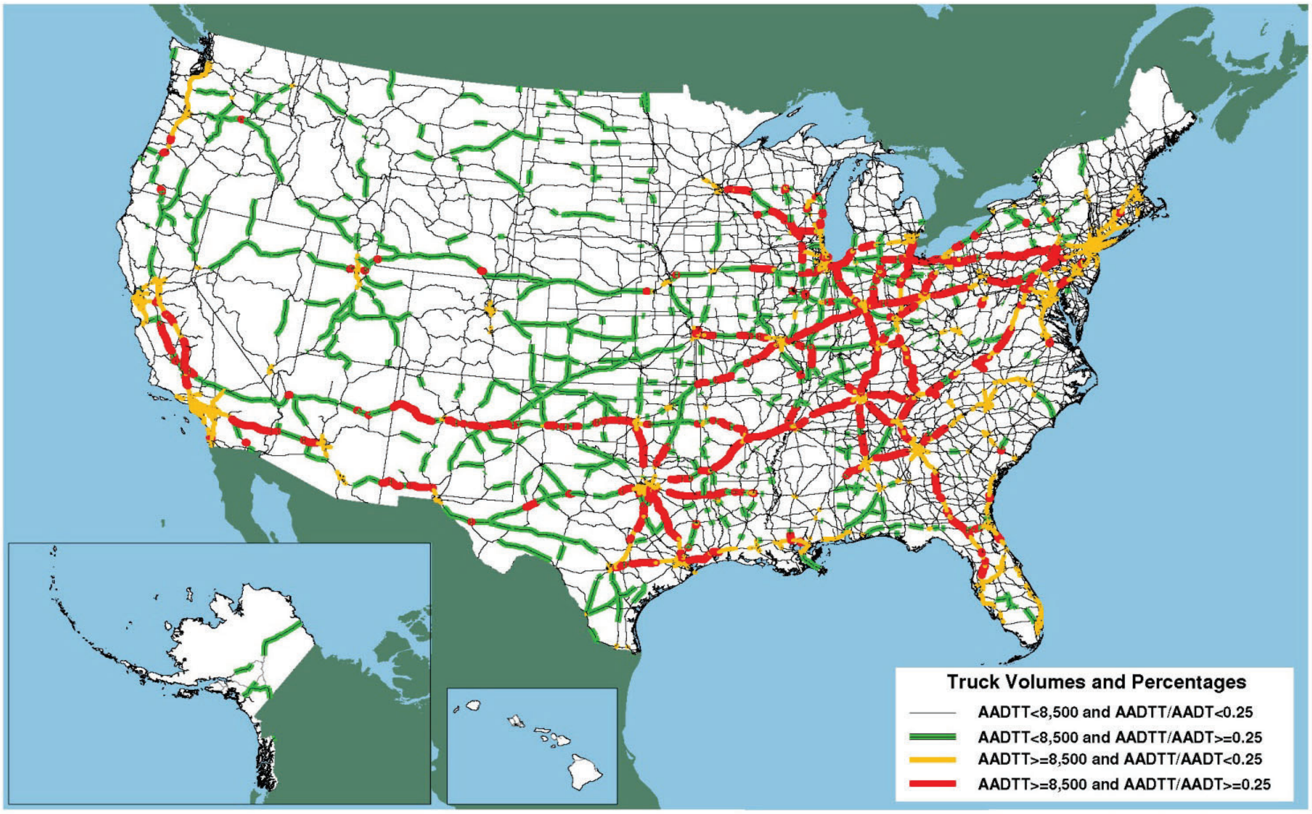
Exhibit 1-26 The Spectrum of Freight Moved in 2007

Parameter	Commodity Type: Value Based	Commodity Type: Tonnage Based
Top Three Commodity Classes	Machinery	Gravel
	Electronics	Cereal Grains
	Motorized Vehicles	Coal
Share of Total Tons	13%	85%
Share of Total Value	65%	30%
Key Performance Variables	Reliability	Reliability
	Speed	Cost
	Flexibility	
Share of Tons by Domestic Mode	87% Truck	71% Truck
	5% Multiple Modes and Mail	12% Rail
	4% Rail	9% Pipeline
		4% Multiple Modes and Mail
		3% Water
Share of Value by Domestic Mode	70% Truck	71% Truck
	16% Multiple Modes and Mail	12% Pipeline
	10% Air	7% Multiple Modes and Mail
	2% Rail	6% Rail
		2% Water

Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Managements and Operations, Freight Analysis Framework, version 3.2, 2011.

Though many freight movements comprise long-distance shipments to domestic or international locations, a larger percentage of shipments, particularly those shipped by truck, are transported shorter distances. Approximately half of all trucks larger than pickups and vans operate locally—within 50 miles of home—and these short-haul trucks account for about 30 percent of truck VMT. By contrast, only 10 percent of trucks larger than pickups and vans operate more than 200 miles away from home, but these trucks account for more than 30 percent of truck VMT. Long-distance truck travel also accounts for nearly all freight ton miles and a large share of truck VMT. More information is shown in *Exhibit 1-28*.

Exhibit 1-27 Major Truck Routes on the National Highway System, 2007



Note: AADTT is the average annual daily truck traffic and includes all freight-hauling and other trucks with six or more tires. AADT is average annual daily traffic and includes all motor vehicles.
Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, version 3.1, 2010.

Exhibit 1-28 Trucks and Truck Miles by Range of Operations

Location	Trucks (percent)	Truck Miles (percent)
Off the road	3.3%	1.6%
50 miles or less	53.3%	29.3%
51 to 100 miles	12.4%	13.2%
101 to 200 miles	4.4%	8.1%
201 to 500 miles	4.2%	12.1%
501 miles or more	5.3%	18.4%
Not reported	13.0%	17.3%
Not applicable	4.1%	0.1%
Total	**100%**	**100%**

Note: Includes trucks registered to companies and individuals in the United States except pickups, minivans, other light vans, and sport utility vehicles. Numbers may not add to total due to rounding.

Source: U.S. Department of Commerce, Census Bureau, 2002 Vehicle Inventory and Use Survey: United States, EC02TV-US, Table 3a (Washington, DC: 2004), available at http://www.census.gov/prod/ec02/ec02tv-us.pdf as of July 31, 2012.

Freight Data Reporting and Ton-Miles

Passenger transportation volumes often use passenger-miles to measure transportation volume. The analogous measure for freight would seem to be ton-miles. Computing freight ton-miles by transportation mode is both difficult and potentially misleading for three reasons: (1) a “ton” of freight varies widely in both the nature and composition of commodities because, unlike passenger miles where a passenger is a fixed unit, for freight a ton of coal is a very different commodity than a ton of frozen ice cream; (2) freight value and tonnage often, though not always, move in opposite directions because lighter-weight goods often have higher value on a per-weight basis and are underrepresented in ton-miles measures while heavier-weight goods often are lower value on a per-weight basis and are overrepresented in ton-miles measures; and (3) ton-miles masks commodity attributes such as value and distance bracket (see *Exhibit 1-28)*, which are important determinants of mode choice.

Although computationally difficult, the Bureau of Transportation Statistics (BTS) has conducted a special tabulation of annual freight ton-miles (1980–2009) for all freight transportation modes (air, truck, railroad, domestic water transportation, and pipeline). *Exhibit 1-29* represents an excerpt from the BTS tabulation and shows that railroad moves make up the largest single mode share with over 35 percent of the ton-miles, since the railroads tend to move heavy commodities over long distances. When considered in isolation the downward shift in truck ton-miles from 2005 to 2009 hides the trend of increasing truck VMT during that same time period.

Exhibit 1-29 **U.S. Ton-Miles of Freight (BTS Special Tabulation) (Millions)**

	2005	2006	2007	2008	2009
TOTAL U.S. ton-miles of freight	**4,570,316**	**4,630,792**	**4,695,555**	**4,647,112**	**4,302,320**
Air	15,745	15,361	15,142	13,774	12,027
Truck	1,291,308	1,291,244	1,403,538	1,429,296	1,321,396
Railroad	1,733,329	1,855,902	1,819,633	1,729,737	1,582,093
Domestic water transportation	591,276	561,629	553,143	520,494	477,122
Pipeline	938,659	906,656	904,101	953,812	909,682

Source: Bureau of Transportation Statistics, National Transportation Statistics, Table 1-50. (http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_50.html).

Freight Transportation and the Cost of Goods

Geographic accessibility of the major freight corridors and the performance of these corridors stimulate economic activity and create jobs. While deregulation and other factors lowered the cost of freight transportation for a given level of service over the past four decades, congestion, rising fuel prices, environmental constraints[1], and other factors could increase the cost of moving all goods in the years ahead. If these factors are not mitigated, the increased cost of moving freight will be felt throughout the economy, affecting businesses and households alike.

The long and often vulnerable supply chains of high-value, time-sensitive commodities are particularly susceptible to congestion. Congestion results in enormous costs to shippers, carriers, and the economy. For example, Nike spends an additional $4 million per week to carry an extra 7 to 14 days of inventory to compensate for shipping delays.[2] One day of delay requires APL's eastbound trans-Pacific services to use an additional 1,300 containers and chassis, which adds $4 million in costs per year.[3] A week-long disruption to container movements through the Ports of Los Angeles and Long Beach could cost the national economy between $65 million and $150 million per day.[4] Freight bottlenecks on highways throughout the United States cause more than 243 million hours of delay to truckers annually.[5] At a delay cost of $26.70 per hour, the conservative value used by the FHWA's Highway Economic Requirements System model for estimating national highway costs and benefits, these bottlenecks cost truckers about $6.5 billion per year.

Congestion costs are compounded by continuing increases in operating costs per mile and per hour. The cost of highway diesel fuel more than doubled in constant dollars over the decade ending in 2011 and would have quadrupled if the prices at the peak in 2008 had continued.[6] Future labor costs are projected to increase at a faster rate than in the past in response to the growing shortage of truck drivers.[7] To attract and retain more drivers, carriers will reduce the number of hours drivers are on the road, which will in turn increase operating costs. Railroads also are facing labor recruitment challenges.[8] Beyond fuel and labor, truck operating costs are affected by needed repairs to damaged equipment caused by deteriorating roads; taxes and tolls to pay for repair of infrastructure; and insurance and additional equipment required to meet security, safety, and environmental requirements.

Increased costs to carriers are reflected eventually in increased prices paid for freight transportation. Between 2003 and 2009, prices increased 17 percent for truck transportation, 36 percent for rail transportation, 16 percent for scheduled air freight, 16 percent for water transportation, 41 percent for pipeline transportation of crude petroleum, 29 percent for other pipeline transportation, and 9 percent for freight transportation support activities.[9]

The importance of freight transportation varies by economic sector. For example, $1 of final demand for agricultural products requires 14.2 cents in transportation services, compared with 9.1 cents for manufactured goods and about 8 cents for mining products.[10] An increase in transportation cost affects inexpensive (on a per-ton basis), cost-sensitive bulk commodities more than high-value, time-sensitive commodities that have higher margins. In either case, an increase in transportation costs will ripple through all these industries, affecting not only the cost of goods from all economic sectors but also markets for the goods.

[1] "Environmental constraints" is primarily meant to include environmental regulations that require the use of cleaner, lower emissions fuels and/or place higher taxes on higher emissions fuels.

[2] John Isbell, "Maritime and Infrastructure Impact on Nike's Inbound Delivery Supply Chain," TRB Freight Roundtable, October 24, 2006 www.trb.org/conferences/FDM/Isbell.pdf.

[3] John Bowe, "The High Cost of Congestion," TRB Freight Roundtable, October 24, 2006 www.trb.org/conferences/FDM/Bowe.pdf.

[4] U.S. Congressional Budget Office, The Economic Costs of Disruptions in Container Shipments, March 26, 2006 www.cbo.gov/ftpdocs/71xx/doc7106/03-29-Container_Shipments.pdf.

[5] FHWA, An Initial Assessment of Freight Bottlenecks on Highways, October 2005 www.fhwa.dot.gov/policy/otps/bottlenecks.

[6] FHWA, Freight Facts and Figures 2011, figure 4-2, page 50.

[7] Inbound Logistics. "Trucking Perspectives, 2013," September 2013 http://www.inboundlogistics.com/cms/article/trucking-perspectives-2013/

[8] Federal Railroad Administration, An Examination of Employee Recruitment and Retention in the U.S. Railroad Industry, 2007 www.fra.dot.gov/us/content/1891.

[9] FHWA, Freight Facts and Figures 2011, table 4-6, page 49.

[10] DOT, Bureau of Transportation Statistics, "The Economic Importance of Transportation Services: Highlights of the Transportation Satellite Accounts," BTS/98-TS4R, April 1998, figure 2, page 5.

Freight Challenges

The challenges of moving the Nation's freight cheaply and reliably on an increasingly constrained infrastructure without affecting safety and degrading the environment are substantial, and traditional strategies to support passenger travel may not provide adequate solutions. The freight transportation challenge differs from that of urban commuting and other passenger travel in several ways:

- Freight often moves long distances through localities and responds to distant economic demands, while the majority of passenger travel occurs between local origins and destinations. Freight movement often creates local problems without local benefits.
- Freight movements fluctuate more quickly and in greater relative amounts than passenger travel. Both passenger travel and freight respond to long-term demographic change, but freight responds more quickly than passenger travel to short-term economic fluctuations. Fluctuations can be national or local. The addition or loss of just one major business can dramatically change the level of freight activity in a locality.
- Freight movement is heterogeneous compared with passenger travel. Patterns of passenger travel tend to be very similar across metropolitan areas and among large economic and social strata. The freight transportation demands of farms, steel mills, and clothing boutiques differ radically from one another. Solutions aimed at average conditions are less likely to work because the freight demands of economic sectors vary widely.
- Improvements targeted at freight demand are needed because freight accounts for a larger share of VMT on the transportation system and improvements targeted at general traffic or passenger travel are less likely to aid the flow of freight except as an incidental by-product.

Local public action is difficult to marshal because freight traffic and the benefits of serving that traffic rarely stay within a single political jurisdiction. One-half of the weight and two-thirds of the value of all freight movements cross a State or international boundary. Federal legislation established metropolitan planning organizations (MPOs) in the 1960s to coordinate transportation planning and investment across State and local lines within urban areas, but freight corridors extend well beyond even the largest metropolitan regions and usually involve several States. Various provisions in MAP-21, most notably the requirement to develop a National Freight Strategic Plan outlined in Section 1115, discuss the need to develop a process to address multi-State projects and encouraging jurisdictions to collaborate with one another to address freight transportation needs. MAP-21 Section 1118, which discusses the development of State freight plans, can assist States and other organizations working with the States to identify freight transportation needs both within the State and also at the States' borders. Creative and ad hoc arrangements are often required through pooled-fund studies and multi-State coalitions to plan and invest in freight corridors that span regions and even the continent, but there are few institutional arrangements that coordinate this activity. One example of a more established multi-State arrangement is the I-95 Corridor Coalition. Additional information about this coalition and similar groups can be found at www.ops.fhwa.dot.gov/freight/corridor_coal.htm.

The growing needs of freight transportation can bring into focus conflicts between interstate and local interests. Many communities do not want the noise and other aspects of trucks and trains that pass through with little benefit to the locality, but those transits can have a huge impact on national freight movement and regional economies.

Challenges for Freight Transportation: Congestion

Congestion affects economic productivity in several ways, including requiring higher but less-productive labor levels, higher inventory levels, increased equipment use, and a larger number of distribution centers serving smaller geographic areas. Workers' commuting time also increases when congestion increases. The growth in freight is a major contributor to congestion in urban areas and on intercity routes, and congestion affects the timeliness and reliability of freight transportation. Growing freight demand increases recurring congestion at freight bottlenecks, places where freight and passenger service conflict with one another, and where there is not enough room for local pickup and delivery. Congested freight hubs include international gateways such as ports, airports, and border crossings, and major domestic terminals and transfer points such as Chicago's rail yards. Bottlenecks between freight hubs are caused by converging traffic at highway intersections and railroad junctions, steep grades on highways and rail lines, lane reductions on highways and single-track portions of railroads, and locks and constrained channels on waterways. A preliminary study for the FHWA identified intersections in large cities, where both personal vehicles and trucks clog the road, as the largest highway freight bottlenecks.[1]

As passenger cars and trucks compete for space on the highway system, commuter and intercity passenger trains compete with freight trains for space on the railroad network. Rail freight is growing at the same time that rising fuel prices and environmental concerns are encouraging greater use of commuter and intercity rail.

Congestion also is caused by restrictions on freight movement, such as the lack of space for trucks in dense urban areas and limited delivery and pickup times at ports, terminals, and shipper loading docks. One estimate of urban congestion attributes 947,000 hours of vehicle delay to delivery trucks parked at curbside in dense urban areas where office buildings and stores lack off-street loading facilities.[2] Limitations on delivery times place significant demands on highway rest areas when large numbers of trucks park outside major metropolitan areas waiting for their destination to open and accept their shipments.[3]

Bottlenecks cause recurring, predictable congestion in various, high transportation volume locations. Additionally, less predictable, non-recurring congestion can also create challenges for freight movements, especially those that are time-sensitive. Sources of nonrecurring delay include traffic incidents, weather, work zones, and other disruptions. These nonrecurring, often-unpredictable, sources of highway delay have been estimated to exceed delay from recurring congestion.[4] Weather, maintenance activities, and incidents have similar effects on aviation, railroads, pipelines, and waterways. Aviation is regularly disrupted by local weather delays; and inland waterways are closed by regional flooding, droughts, and ice.

Chapter 5 includes a broader discussion of system performance, including congestion's impacts on system performance.

[1] FHWA, An Initial Assessment of Freight Bottlenecks on Highways, October 2005 www.fhwa.dot.gov/policy/otps/bottlenecks.

[2] Oak Ridge National Laboratory, Temporary Losses of Highway Capacity and Impacts on Performance: Phase 2, 2004, table 36, page 88 www-cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2004_209.pdf.

[3] FHWA, Study of Adequacy of Commercial Truck Parking Facilities, 2002 http://www.fhwa.dot.gov/publications/research/safety/01158/index.cfm.

[4] Oak Ridge National Laboratory, Temporary Losses of Highway Capacity and Impacts on Performance: Phase 2, 2004, table 41, page 101 www-cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2004_209.pdf.

Challenges for Freight Transportation: Safety, Energy, and the Environment

Freight transportation is not just an issue of product throughput and congestion. The growth in freight movement has heightened public concerns about safety, energy consumption, and the environment.

Highways and railroads account for nearly all fatalities and injuries involving freight transportation. Most of these fatalities involve people who are not part of the freight transportation industry, such as trespassers at railroad facilities and occupants of other vehicles killed in crashes involving large trucks. The FHWA's Freight Facts and Figures 2011 publication shows that, of the 33,808 highway fatalities in 2009, 1.5 percent were occupants of large trucks and 7.5 percent were others killed in crashes involving large trucks (the remaining 91 percent of fatalities were attributed to other types of personal and commercial vehicles). Chapter 5 of Freight Facts and Figures 2011 discusses highway safety in more detail.

According to Freight Facts and Figures 2011, single-unit and combination trucks accounted for 26 percent of all gasoline, diesel, and other fuels consumed by motor vehicles, and 74 percent of the fuel consumed by freight transportation in 2009. Fuel consumption by trucks resulted in 78 percent of the 365.6 million metric tons of carbon dioxide (CO_2) equivalent generated by freight transportation, and freight accounted for 26 percent of transportation's contribution to this major greenhouse gas. Trucks and other heavy vehicles that operate on the U.S. highway system also are a major contributor to air-quality problems related to nitrogen oxide (NO_x) (33 percent of all mobile sources) and particulate matter of 10 microns in diameter or smaller (PM-10) (23.3 percent of all mobile sources). Freight modes combined account for 49 percent of all mobile sources of NO_x and 36 percent of all mobile sources of PM-10.

Environmental issues involving freight transportation go well beyond emissions. Disposal of dredge spoil, the mud and silt that must be removed to deepen water channels for commercial vessels, is a major challenge for allowing larger ships to berth. Land-use and water-quality concerns are raised against all types of freight facilities, and invasive species can spread through freight movement.

Incidents involving hazardous materials exacerbate public concern and cause real disruption. Freight Facts and Figures 2011 shows that, of the 14,783 accident-related hazardous materials transportation incidents in 2010, highways accounted for 12,635 accidents, air accounted for 1,293 accidents, rail accounted for 750 accidents, and water accounted for 105 accidents. The railcar fire in the Howard Street tunnel under Baltimore City in 2001 illustrates the perceived and real problems of transporting hazardous materials. This incident, which occurred on tracks next to a major league baseball stadium at game time during the evening rush hour, forced the evacuation of thousands of people and closed businesses in much of downtown Baltimore. A vital railroad link between the Northeast and the South, as well as a local rail transit line and all east-west arterial streets through downtown, were closed for an extended period.

Beyond the challenges of intergovernmental coordination, freight transportation raises additional issues involving the relationships between public and private sectors. Virtually all carriers and many freight facilities are privately owned. Freight Facts and Figures 2011 shows that the private sector owns $1.001 trillion in transportation equipment plus $656 billion in transportation structures. In comparison, public agencies own $592 billion in transportation equipment plus $2.94 trillion in highways. Freight railroad facilities and services are owned almost entirely by the private sector, while trucks owned by the private sector operate over public highways. Likewise, air cargo services owned by the private sector operate in public airways and mostly at public airports. Privately owned ships operate over public waterways and at both public and private port facilities. Most pipelines are privately owned but significantly controlled by public regulation. In the public sector, virtually all truck routes are owned by State or local governments, and airports and harbors are typically owned by regional or local authorities. Air and water navigation is typically handled at the Federal level, and safety is regulated by all levels of government. As a consequence of this mixed ownership and management, most solutions to freight problems require joint action by both public and private sectors. Financial, planning, and other institutional mechanisms for developing and implementing joint efforts have been limited, inhibiting effective measures to improve the performance and minimize the public costs of the freight transportation system. In an effort to address these challenges, MAP-21 Section 1117 encourages the

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National Freight Policy

The recent passage of the Moving Ahead for Progress in the 21st Century (MAP-21) transportation reauthorization created a formal U.S. policy to improve the condition and performance of the national freight network to ensure that it allows the United States to compete in the global economy and achieve various goals that will improve freight movement in the U.S. (Section 1115). This policy greatly increases the visibility and emphasis on freight transportation at the federal level. MAP-21 requires the designation of a primary freight network, the creation of a critical rural freight corridors designation, the creation of a national freight strategic plan, the creation of a freight conditions and performance report, and the creation of new or refinement of existing transportation investment and planning tools to evaluate freight-related and nonfreight-related projects. All of these provisions, as well as other related provisions in MAP-21—such as prioritizing of projects to improve freight movement (Section 1116)—encouraging States to establish freight advisory committees (Section 1117), encouraging States to develop State freight plans (Section 1118), and requiring the creation of freight performance measures and performance targets that the States will use to assess freight movement on the Interstate System (Section 1203)—will increase the focus on addressing and improving freight transportation at the Federal, State, and regional/metropolitan levels. Many States and Metropolitan Planning Organizations (MPOs) were already engaged in formal or informal freight transportation planning efforts prior to the adoption of MAP-21, but the new reauthorization bill will help formalize these efforts.

A U.S. DOT Freight Policy Council composed of multi-modal DOT leadership has been created to coordinate the implementation of MAP-21 freight provisions, develop a national freight policy for improving freight movement, and meet the President's goal of doubling U.S. exports by 2015. This new council will create a national freight strategic vision to allow the U.S. to better address infrastructure projects focused on the movement of goods and to enhance the Nation's economic competitiveness in the global economy.

Although the Freight Policy Council is a newly created group, significant efforts had already taken place prior to MAP-21's passage to better understand freight activities and address freight challenges at all levels of government and in the private sector. The results of these efforts may be able to be leveraged by the Freight Policy Council. The Transportation Research Board convened individuals from transportation providers, shippers, State agencies, port authorities, and the U.S. DOT to form a Freight Transportation Industry Roundtable. Members of the roundtable developed an initial Framework for a National Freight Policy to identify freight activities and focus those activities toward common objectives. The framework continues to evolve within the U.S. DOT as part of its outreach to members of the freight community.

creation of State freight advisory committees composed of public and private sector freight stakeholders to help States identify key freight transportation needs within their jurisdictions and across State boundaries. Likewise, MPOs can form their own freight advisory committees to engage public and private sector freight professionals to identify and address freight transportation needs within their metropolitan areas.

Freight challenges are not new, but their ongoing importance and increased complexity warrant creative solutions by all with a stake in the vitality of the American economy.

CHAPTER 2

System Characteristics

Highway System Characteristics

The Nation's extensive network of roadways facilitates the movement of people and goods, promotes the growth of the American economy, provides access to national and international markets, and supports national defense by providing the means for the rapid deployment of military forces and their support systems.

This section explores the characteristics of the Nation's roadways in terms of ownership, purpose, and usage. Information is presented for the National Highway System (NHS), including its Interstate Highway System component, and for the overall highway system. Separate statistics are also presented for Federal-aid highways, which include roadways that are generally eligible for Federal assistance under current law. Subsequent sections within this chapter explore the characteristics of bridges and transit systems.

Statistics reported in this section draw upon data collected from States through the Highway Performance Monitoring System (HPMS). The terms highways, roadways, and roads are generally used interchangeably in this section and elsewhere in the report. Roadways within a community with a population of 5,000 or more are classified as urban while roadways in areas outside urban boundaries are classified as rural. Some statistics in this section are presented separately for small urban areas that have populations of 5,000 to 49,999 and urbanized areas with populations over 50,000.

Q&A

Are the 2010 HPMS data cited in this report fully consistent with those reported in the *Highway Statistics 2010* publication?

No. The statistics reflected in this report are based on the latest available 2010 HPMS data as of the date the chapters were written, and include revisions that were not reflected in the *Highway Statistics 2010* publication.

The HPMS database is subject to further change on an ongoing basis if States identify a need to revise their data. Such changes will be reflected in the next edition of the C&P report.

Additional information on HPMS is available at http://www.fhwa.dot.gov/policy/ohpi/hpms/index.htm.

Roads by Ownership

As shown in *Exhibit 2-1*, local governments owned approximately 77.5 percent of the Nation's public road mileage in 2010. Local governments generally construct and maintain these roads themselves, but some enter into agreements with the State Departments of Transportation (DOTs) to perform these functions on their behalf. In 2010, State governments owned 19.1 percent of the Nation's public road mileage. The remaining 3.4 percent of total public road mileage was under the control of the Federal government in 2010 and was located primarily in National Parks and Forests, on Indian reservations, and on military bases. These figures do not reflect privately owned roads or roads not available for use by the general public.

The highway system in the Nation comprised nearly 4.08 million miles in 2010, up from 3.95 million miles in 2000. Total mileage in urban areas grew by an average annual rate of 2.5 percent between 2000 and 2010. However, highway miles in rural areas decreased at an average annual rate of 0.4 percent during the same time period.

In addition to the construction of new roads, two factors have continued to contribute to the increase of urban highway mileage. First, based on the 2000 decennial census, the boundaries of urban areas have expanded resulting in the reclassification of some mileage from rural to urban. States implemented these boundary changes in their HPMS data reporting gradually. As a result, the impact of the census-based changes on these statistics is not confined to a single year. Second, greater focus has been placed on Federal

Exhibit 2-1 Highway Miles by Owner and by Size of Area, 2000–2010

	2000	2002	2004	2006	2008	2010	Annual Rate of Change 2010/2000
Rural Areas (under 5,000 in population)							
Federal	116,707	117,775	117,762	123,393	124,482	128,004	0.9%
State *	663,763	664,814	649,582	636,142	632,679	626,823	-0.6%
Local	2,311,263	2,297,168	2,236,101	2,230,946	2,223,172	2,220,153	-0.4%
Subtotal Rural Areas	**3,091,733**	**3,079,757**	**3,003,445**	**2,990,481**	**2,980,333**	**2,974,980**	**-0.4%**
Urban Areas (5,000 or more in population)							
Federal	1,484	2,820	3,570	4,988	7,077	8,769	19.4%
State *	111,540	111,774	129,661	147,501	151,631	152,666	3.2%
Local	746,344	787,319	860,786	890,038	920,299	938,955	2.3%
Subtotal Urbanized Areas	**859,368**	**901,913**	**994,017**	**1,042,527**	**1,079,007**	**1,100,390**	**2.5%**
Total Highway Miles							
Federal	118,191	120,595	121,332	128,381	131,559	136,773	1.5%
State *	775,303	776,588	779,243	783,643	784,310	779,489	0.1%
Local	3,057,607	3,084,487	3,096,887	3,120,984	3,143,471	3,159,107	0.3%
Total	**3,951,101**	**3,981,670**	**3,997,462**	**4,033,008**	**4,059,340**	**4,075,370**	**0.3%**
Percentage of Total Highway Miles							
Federal	3.0%	3.0%	3.0%	3.2%	3.2%	3.4%	
State *	19.6%	19.5%	19.5%	19.4%	19.3%	19.1%	
Local	77.4%	77.5%	77.5%	77.4%	77.4%	77.5%	
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	

** Amounts shown include mileage owned by State highway agencies only; mileage owned by other State entities is combined with local mileage.*

Source: Highway Performance Monitoring System (as of November 2012).

agencies to provide a more complete reporting of Federally owned mileage. As a result, reported Federal mileage in urban areas increased at an average annual rate of 19.4 percent from 2000 to 2010. This is due primarily to more accurate reporting of Department of Defense mileage on military bases within urban areas. In rural areas, Federally owned mileage increased at an annual rate of 0.9 percent over the same period. Chapter 11 provides additional details on roads serving Federal Lands.

Roads by Purpose

Roads are often classified by the purpose they serve, which is commonly called functional classification. *Exhibit 2-2* shows the hierarchy of the Highway Functional Classification System (HFCS), which is used extensively in this report in the presentation of highway and bridge statistics.

Review of Functional Classification Concepts

Roads serve two important functions: providing access and providing mobility. Much like an equilibrium point, typically the better any individual segment is at serving one of these functions, the worse it is at serving the other. Routes on the Interstate Highway System allow a driver to travel long distances in a relatively short time, but do not allow the driver to enter each property along the way. Contrarily, a subdivision street allows a driver access to any address along its length, but does not allow the driver to travel at high speeds and involves frequent interruption by intersections that often contain traffic control devices.

The principal arterial system consists of Interstate, Other Freeways & Expressways, and Other Principal Arterial roads. These roads provide the highest level of mobility at the highest speed for long, uninterrupted travel. They typically have higher design standards than other roads because they often include multiple lanes and have some degree of access control. The principal arterial system provides interstate and intercounty service so that all developed areas are within a reasonable distance of an arterial highway. Most urban areas (with populations greater than 25,000) have rural principal arterial highways and rural other freeways and expressways connections with virtually all urbanized areas (with populations greater than 50,000). The principal arterial system serves major metropolitan centers, corridors with the highest traffic volumes, and trips of longer lengths. It carries most trips entering and leaving metropolitan areas and provides continuity for roadways that cross urban boundaries.

Exhibit 2-2 Revised Highway Functional Classification

Arterial
Principal Arterial
Interstate
Other Freeway & Expressway (OF&E)
Other Principal Arterial (OPA)
Minor Arterial
Collector
Major Collector
Minor Collector
Local
Local

Note: Rural and Urban classifications have now been synchronized. Previously, urban collectors were not broken down into separate categories for major and minor, and rural OF&Es were included as part of rural OPAs. Some exhibits presented in this report still use the old classifications.

Source: FHWA.

Minor arterial routes provide service for trips of moderate length at a lower level of mobility. They provide a connection between collector roadways and the principal arterial highways.

Collectors provide a lower degree of mobility than arterials. They are designed for travel at lower speeds and for shorter distances. Generally, collectors are two-lane roads that collect traffic from local roads and distribute it to the minor arterial system. The collector system is stratified into two subsystems: major and minor. Major collectors serve larger towns not accessed by higher-order roads, and important industrial, commercial, or agricultural areas that generate significant traffic but are not served by arterials. Minor collectors are typically spaced at intervals consistent with population density to collect traffic from local roads and to ensure that a collector road serves smaller population areas.

Unlike arterials, collector roads may penetrate residential communities, distributing traffic from the arterials to the ultimate destination for many motorists. Collectors also channel traffic from local streets onto the arterial system. Local roads represent the largest element in the American public road system in terms of mileage. All public roads below the collector system are considered local. Local roads provide basic access between residential and commercial properties, connecting with higher-order highways.

The distinction between those roads functionally classified as local and locally owned roads is important to note. Some roads functionally classified as local are owned by the Federal or State government, while local governments own some arterials and collectors as well as a large percentage of roads functionally classified as local.

Exhibit 2-3 provides a graphic representation of the percentage of the cumulative distribution of mileage by average annual daily traffic (AADT) volume group for some individual functional classes, ranging from major collectors to Interstates. Higher-ordered systems, such as Interstates, tend to carry more traffic than lower-ordered systems, and urban routes tend to carry more traffic than rural routes with comparable functional class designations.

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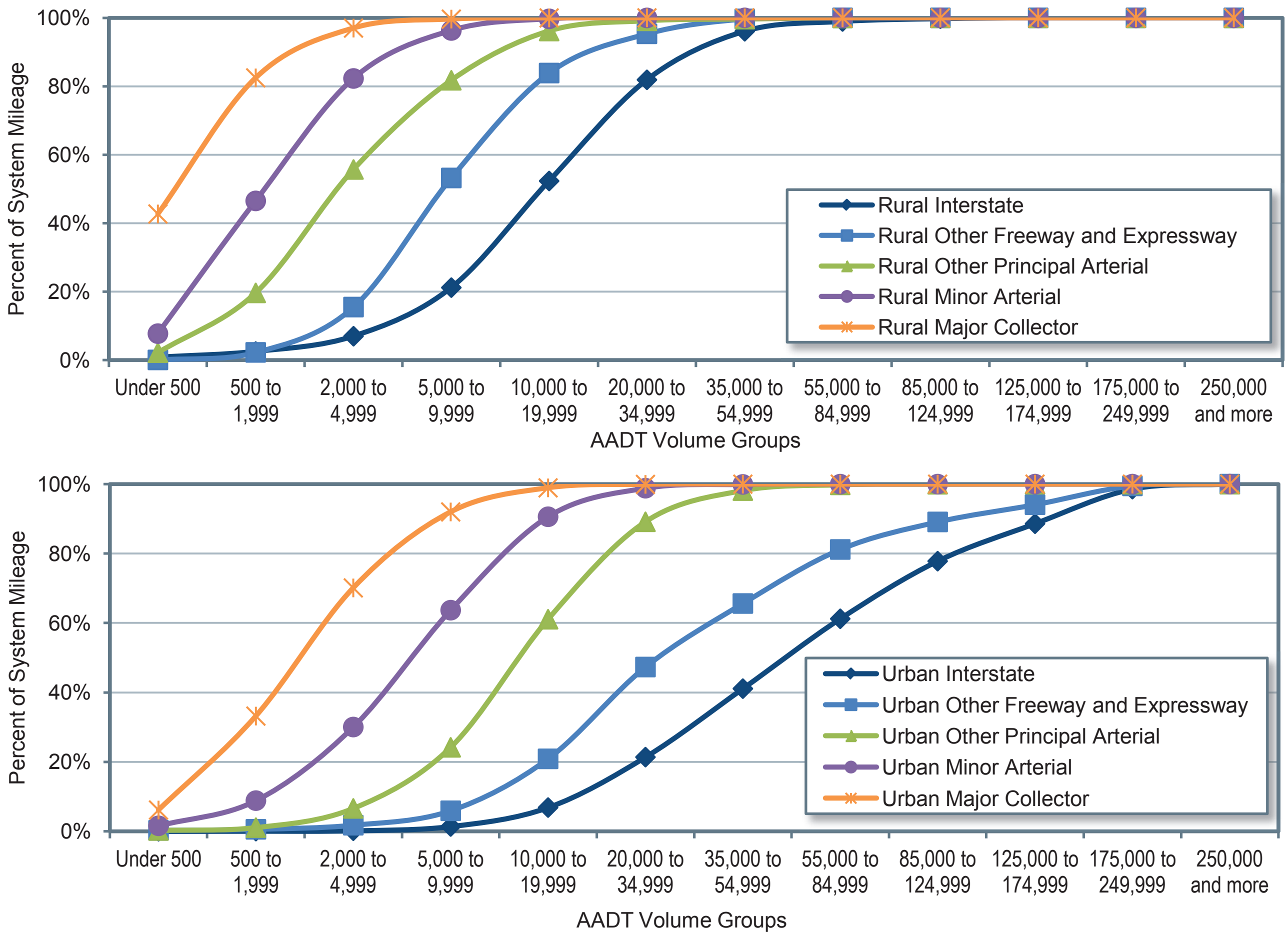
Exhibit 2-3 **Cumulative Percentage Distributions of Mileage by AADT Volume, by Functional System**



Source: 2010 HPMS Database.

System Characteristics

Exhibit 2-4 summarizes the percentage of highway route miles, lane miles, and vehicle miles traveled (VMT) for 2010 broken down by functional system and by population area. Route miles represent the length of a roadway, while lane miles represent the length of the roadway multiplied by the number of lanes on that roadway. As noted earlier, rural areas have populations of less than 5,000, small urban areas have populations between 5,000 and 49,999, and urbanized areas have populations of 50,000 or more.

The majority of the Nation's highway miles and lane miles, 72.7 percent and 70.8 percent, respectively, were located in rural areas in 2010. However, only 32.9 percent of the VMT occurred on these roadways. Roads classified as rural local constituted slightly over one-half of all highway mileage, but carried only 4.5 percent of total VMT.

Roads in small urban areas accounted for 5.2 percent of highway mileage, 5.3 percent of lane miles, and 7.4 percent of VMT. Urbanized areas only constituted 22.1 percent of the Nation's total highway mileage and 23.9 percent of lane miles despite carrying 59.8 percent of the Nation's VMT in 2010. Urbanized Interstate System highways made up only 0.4 percent of total route mileage, but carried 14.9 percent of total VMT—the greatest amount of all functional classifications.

Exhibit 2-4 **Percentage of Highway Miles, Lane Miles, and VMT by Functional System**

Functional System	Miles	Lane Miles	VMT
Rural Areas (less than 5,000 in population)			
Interstate	0.7%	1.4%	8.2%
Other Freeway and Expressway	0.1%	0.2%	0.6%
Other Principal Arterial	2.2%	2.7%	6.8%
Minor Arterial	3.3%	3.3%	5.1%
Major Collector	10.2%	9.8%	6.0%
Minor Collector	6.4%	6.1%	1.8%
Local	49.7%	47.3%	4.5%
Subtotal Rural Areas	**72.7%**	**70.8%**	**32.9%**
Small Urban Areas (5,000–49,999 in population)			
Interstate	0.1%	0.1%	1.1%
Other Freeway and Expressway	0.0%	0.1%	0.3%
Other Principal Arterial	0.4%	0.5%	2.1%
Minor Arterial	0.5%	0.6%	1.7%
Major Collector	0.6%	0.6%	0.9%
Minor Collector	0.0%	0.0%	0.0%
Local	3.6%	3.4%	1.2%
Subtotal Small Urban Areas	**5.2%**	**5.3%**	**7.4%**
Urbanized Areas (50,000 or more in population)			
Interstate	0.4%	1.0%	14.9%
Other Freeway and Expressway	0.2%	0.5%	6.4%
Other Principal Arterial	1.2%	2.2%	13.4%
Minor Arterial	2.1%	2.7%	11.3%
Major Collector	2.2%	2.2%	5.2%
Minor Collector	0.0%	0.0%	0.0%
Local	16.0%	15.2%	8.5%
Subtotal Urbanized Areas	**22.1%**	**23.9%**	**59.8%**
Total	**100.0%**	**100.0%**	**100.0%**

Source: Highway Performance Monitoring System as of December 2011.

Pedestrian and Bicycle Elements

Improving pedestrian and bicycle data collection and analysis and developing quantitative analysis methods and tools are core elements of FHWA's programmatic efforts. FHWA has initiated several efforts to develop better pedestrian and bicycle data and to begin to incorporate multimodal data into existing data management systems. For example, the most recent release of the Traffic Monitoring Guide includes recommendations for conducting bicycle and pedestrian counts, and it specifies a standard set of data fields for reporting the counts. In addition, FHWA maintains a system called the Traffic Monitoring Analysis System (TMAS), which receives raw data and computes basic reports from those data. FHWA has funded a project that will modify TMAS to receive and report on bicycle and pedestrian counts based on the Traffic Monitoring Guide format. These enhancements will be included in the next version of TMAS (Version 3.0), which is scheduled to be released in early 2015. FHWA is also exploring the feasibility of building regional bicycle and pedestrian-count databases to simplify access to TMAS and to provide public access to the data.

Third-party efforts such as the Household Travel Survey and the National Bicycle and Pedestrian Documentation Project generate multimodal data and external benchmarking resources. For example, *Bicycling and Walking in the U.S.: 2012 Benchmarking Report* is an ongoing effort by the Alliance for Biking and Walking to collect and analyze data on bicycling and walking in all 50 states and the 51 largest U.S. cities. The biennial report includes data such as bicycling and walking levels and demographics, bicycle and pedestrian safety, funding for bicycle and pedestrian projects, written policies on bicycling and walking, bicycle infrastructure, bike-transit integration, bicycling and walking education and encouragement activities, public health indicators, and the economic impact of bicycling and walking.

Exhibit 2-5 shows trends in public road route mileage from 2000 to 2010. Overall route mileage increased by 132,667 between 2000 and 2010, an annual growth rate of 0.3 percent. From 2000 to 2010, the number of rural route miles declined by 111,253. Urban route miles increased 243,920 route miles during the same period. Among functional classes, rural local roads had the largest decrease in route mileage with a reduction of 78,303. Urban local roads had the largest growth in route mileage with an increase of 178,281.

As noted earlier, the decline in rural route mileage can be partially attributed to changes in urban boundaries resulting from the 2000 Census. These boundary changes have also affected the classification of lane mileage and VMT.

Exhibit 2-5 Highway Route Miles by Functional System, 2000–2010

Functional System	2000	2002	2004	2006	2008	2010	Annual Rate of Change 2010/2000
Rural Areas (less than 5,000 in population)							
Interstate	33,152	33,107	31,477	30,615	30,227	30,260	-0.9%
Other Freeway & Expressway*						3,299	N/A
Other Principal Arterial*						92,131	N/A
Other Principal Arterial*	99,023	98,945	95,998	95,009	95,002		N/A
Minor Arterial	137,863	137,855	135,683	135,589	135,256	135,681	-0.2%
Major Collector	433,926	431,754	420,293	419,289	418,473	418,848	-0.4%
Minor Collector	272,477	271,371	268,088	262,966	262,852	263,271	-0.3%
Local	2,115,293	2,106,725	2,051,902	2,046,796	2,038,517	2,036,990	-0.4%
Subtotal Rural Areas	**3,091,733**	**3,079,757**	**3,003,441**	**2,990,264**	**2,980,327**	**2,980,480**	**-0.4%**
Urban Areas (5,000 or more in population)							
Interstate	13,523	13,640	15,359	16,277	16,789	16,922	2.3%
Other Freeway and Expressway	9,196	9,377	10,305	10,817	11,401	11,371	2.1%
Other Principal Arterial	53,558	53,680	60,088	63,180	64,948	65,505	2.0%
Minor Arterial	90,302	90,922	98,447	103,678	107,182	108,375	1.8%
Collector*	88,798	89,846	103,387	109,639	115,087		N/A
Major Collector*						115,538	N/A
Minor Collector*						3,303	N/A
Local	603,992	644,449	706,436	738,156	763,618	782,273	2.6%
Subtotal Urban Areas	**859,368**	**901,913**	**994,021**	**1,041,747**	**1,079,025**	**1,103,288**	**2.5%**
Total Highway Route Miles	**3,951,101**	**3,981,670**	**3,997,462**	**4,032,011**	**4,059,352**	**4,083,768**	**0.3%**

** 2010 data reflects revised HPMS functional classifications. Rural Other Freeways and Expressways have been split out of the Rural Other Principal Arterial category, and Urban Collect has been split into Urban Major Collector and Urban Minor Collector.*

Source: Highway Performance Monitoring System (as of December 2011).

Tunnels

In 2003, FHWA conducted a survey regarding tunnel inventories. Of the 45 tunnel owners contacted, 40 responded; the survey results suggest that there are approximately 350 highway tunnel bores in the United States.

It should be noted that there is not a one-to-one correspondence between the number of bores and the number of tunnels. For example, while the Sumner Tunnel in Boston consists of a single bore, some tunnels, such as the Hampton Roads Bridge-Tunnel in Norfolk, include two bores.

A National Tunnel Inspection Standards regulation is under development and is scheduled for publication in the spring of 2014. Data gathered as part of this regulation are expected to provide the basis for improved reporting on tunnels in future editions of the C&P report.

Exhibit 2-6 shows the number of highway lane miles by functional system and by population area. Between 2000 and 2010, lane miles on the Nation's highways have grown at an average annual rate of 0.4 percent, from approximately 8.3 million to 8.6 million. The number of lane miles in rural areas decreased by 200,443 during this period, while urban area lane mileage increased by 561,133. Among individual functional classes, urban local roads had the largest increase in the number of lane miles, with 356,562 added between 2000 and 2010.

Exhibit 2-6 Highway Lane Miles by Functional System and by Size of Area, 2000–2010

Functional System	Highway Lane Miles 2000	2002	2004	2006	2008	2010	Annual Rate of Change 2010/2000
Rural Areas (less than 5,000 in population)							
Interstate	135,000	135,032	128,012	124,506	122,956	123,762	-0.9%
Other Freeway and Expressway*						11,907	N/A
Other Principal Arterial*						243,065	N/A
Other Principal Arterial*	253,586	256,458	249,480	248,334	250,153		N/A
Minor Arterial	287,750	288,391	283,173	282,397	281,071	287,761	0.0%
Major Collector	872,672	868,977	845,513	843,262	841,353	857,091	-0.2%
Minor Collector	544,954	542,739	536,177	525,932	525,705	526,540	-0.3%
Local	4,230,588	4,213,448	4,103,804	4,093,592	4,077,032	4,073,980	-0.4%
Subtotal Rural Areas	**6,324,550**	**6,305,044**	**6,146,159**	**6,118,023**	**6,098,270**	**6,124,107**	**-0.3%**
Urban Areas (5,000 or more in population)							
Interstate	74,647	75,864	84,016	89,036	91,924	93,403	2.3%
Other Freeway and Expressway	42,055	43,467	47,770	50,205	53,073	53,231	2.4%
Other Principal Arterial	187,030	188,525	210,506	221,622	228,792	235,127	2.3%
Minor Arterial	229,410	233,194	250,769	269,912	274,225	285,954	2.2%
Collector*	189,839	192,115	220,177	235,240	245,262		N/A
Major Collector*						252,435	N/A
Minor Collector*						7,404	N/A
Local	1,207,984	1,288,898	1,412,872	1,476,314	1,527,230	1,564,546	2.6%
Subtotal Urban Areas	**1,930,966**	**2,022,064**	**2,226,111**	**2,342,329**	**2,420,506**	**2,492,099**	**2.6%**
Total Highway Lane Miles	**8,255,516**	**8,327,108**	**8,372,270**	**8,460,352**	**8,518,776**	**8,616,206**	**0.4%**

** 2010 data reflects revised HPMS functional classifications. Rural Other Freeways and Expressways have been split out of the Rural Other Principal Arterial category, and Urban Collect has been split into Urban Major Collector and Urban Minor Collector.*

Source: Highway Performance Monitoring System - December 2011.

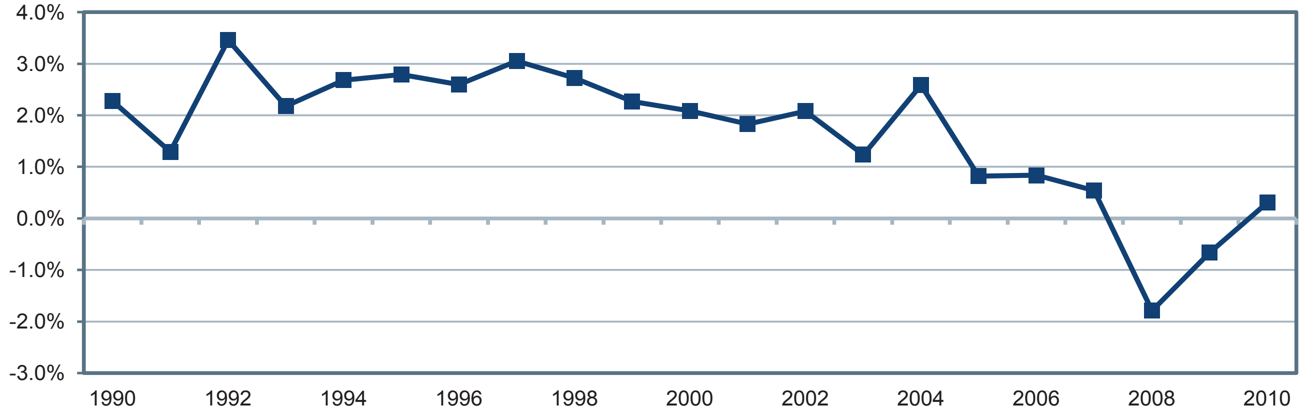
Highway Travel

Total highway VMT grew by 0.31 percent in 2010 relative to 2009. As shown in *Exhibit 2-7*, this small increase followed declines of 1.79 percent in 2008 and 0.66 percent in 2009. These negative growth rates can be partially attributed to the recent period of economic contraction from December 2007 to June 2009 identified by the Business Cycle Dating Committee of the National Bureau of Economic Research (NBER). However, it should be noted that VMT growth had previously been trending downwards; annual VMT growth rate last exceeded 3 percent in 1997 and has not exceeded 1 percent in any year since 2004.

Exhibit 2-8 shows trends in VMT and passenger miles traveled (PMT) by functional class since 2000; VMT measures the number of vehicle miles traveled and PMT weights the travel by the number of occupants of those vehicles. Between 2000 and 2010, VMT grew at an average annual rate of 0.8 percent per year from 2.76 trillion to 2.99 trillion. Estimated total PMT declined over this 10-year period by 0.3 percent per year, decreasing to a total of 4.2 trillion in 2010.

VMT in rural areas totaled 0.99 trillion in 2010. From 2000 to 2010, travel declined on all rural functional classifications except for roads classified as rural local. Rural major collectors experienced the largest percentage reduction in VMT, declining at an average annual rate of 1.8 percent over this period. As noted earlier, the decline in rural VMT can be partially attributed to the expansion of urban boundaries resulting from the 2000 Census.

Exhibit 2-7 **Annual VMT Growth Rates, 1990–2010**



Source: Highway Statistics, various years, Tables VM-1 (United States) and VM-2 (Puerto Rico).

Exhibit 2-8 **Vehicle Miles Traveled (VMT) and Passenger Miles Traveled (PMT), 2000–2010**

	Annual Travel Distance (Millions of Miles)						Annual Rate of Change
Functional System	**2000**	**2002**	**2004**	**2006**	**2008**	**2010**	**2010/2000**
Rural Areas (less than 5,000 in population)							
Interstate	269,533	281,461	267,397	258,324	243,693	246,109	-0.9%
Other Freeway & Expressway[2]						19,603	N/A
Other Principal Arterial[2]						205,961	N/A
Other Principal Arterial[2]	249,177	258,009	241,282	232,224	222,555		N/A
Minor Arterial	172,772	177,139	169,168	162,889	152,246	151,307	-1.3%
Major Collector	210,595	214,463	200,926	193,423	186,275	176,301	-1.8%
Minor Collector	58,183	62,144	60,278	58,229	55,164	53,339	-0.9%
Local	127,560	139,892	132,474	133,378	131,796	132,827	0.4%
Subtotal Rural Areas	**1,087,820**	**1,133,107**	**1,071,524**	**1,038,467**	**991,729**	**985,447**	**-1.0%**
Urban Areas (5,000 or more in population)							
Interstate	397,176	412,481	459,767	482,677	481,520	482,726	2.0%
Other Freeway and Expressway	178,185	190,641	209,084	218,411	223,837	221,902	2.2%
Other Principal Arterial	401,356	410,926	453,868	470,423	465,965	460,753	1.4%
Minor Arterial	326,889	341,958	365,807	380,069	380,734	378,048	1.5%
Collector[2]	137,007	143,621	164,330	175,516	177,665		N/A
Major Collector[2]						178,909	N/A
Minor Collector[2]						3,837	N/A
Local	236,051	241,721	257,617	268,394	271,329	273,474	1.5%
Subtotal Urban Areas	**1,676,664**	**1,741,348**	**1,910,473**	**1,995,489**	**2,001,050**	**1,999,648**	**1.8%**
Total VMT	**2,764,484**	**2,874,455**	**2,981,998**	**3,033,957**	**2,992,779**	**2,985,095**	**0.8%**
Total PMT[1]	**4,390,076**	**4,667,038**	**4,832,394**	**4,933,689**	**4,871,683**	**4,244,157**	**-0.3%**

[1] Assumes approximately 1.59 passengers per vehicle per mile in 2000 and approximately 1.63 passengers per vehicle per mile in 2002, 2004, 2006, and 2008 and approximately 1.42 passengers per vehicle mile for 2010.

[2] 2010 data reflects revised HPMS functional classifications. Rural Other Freeways and Expressways have been split out of the Rural Other Principal Arterial category, and Urban Collect has been split into Urban Major Collector and Urban Minor Collector.

Sources: VMT data from Highway Performance Monitoring System; PMT data from Highway Statistics, Table VM-1.

What has happened to highway travel since 2010?

Q&A

The December 2011 Traffic Volume Trends (TVT) report showed an estimated decrease in VMT of 1.2 percent between 2010 and 2011. VMT on rural Interstates and other rural arterials decreased by 1.5 percent and 1.4 percent, respectively. VMT on other rural roads increased by 1.8 percent, and VMT on urban Interstates decreased by 0.5 percent. VMT on other urban arterials decreased by 1.1 percent, while VMT on other urban roads decreased by 1.2 percent. These numbers are subject to revision when the 2011 HPMS submittals are processed and analyzed.

The May 2012 TVT report shows an increase in travel for the first 5 months of 2012 compared to the same months in 2011. Overall VMT is estimated to have increased by 1.2 percent. VMT on rural Interstate, other arterials, and other rural roads increased by 1.8 percent, 1.2 percent, and 1.8 percent, respectively. VMT on urban Interstates, other urban arterials, and other urban roads increased 1.6 percent, 1.0 percent, and 0.8 percent, respectively.

The TVT report is a monthly report based on hourly traffic count data. These data, collected at approximately 4,000 continuous traffic-counting locations nationwide, are used to calculate the percent change in traffic for the current month compared to the same month in the previous year. Because of limited TVT sample sizes, caution should be used with these estimates.

For additional information on ongoing traffic trends, visit http://www.fhwa.dot.gov/ohim/tvtw/tvtfaq.cfm.

VMT in urban areas totaled approximately 2.00 trillion in 2010. Urban VMT increased at an average annual rate of 1.8 percent over the 10-year period. In 2010, urban interstates carried a bit less than half a trillion VMT, the highest level among any functional class.

Exhibit 2-9 depicts highway travel by functional classification and vehicle type in 2008 and 2010. Three types of vehicles are identified: passenger vehicles which include motorcycles, buses, and light trucks (two-axle, four-tire models); single-unit trucks having six or more tires; and combination trucks, including trailers and semitrailers. Passenger vehicle travel accounted for 90.3 percent of total VMT in 2010; combination trucks accounted for 5.9 percent of VMT during this period and single-unit trucks accounted for the remaining 3.7 percent. The share of truck travel on the rural interstates is considerably higher; in 2010, single-unit and combination trucks together accounted for 24.6 percent of total VMT on the rural Interstates.

Exhibit 2-9 Highway Travel by Functional System and by Vehicle Type, 2008–2010

Functional System	2008	2010	Annual Rate of Change 2010/2008
Rural			
Interstate			
PV	181,278	185,212	1.1%
SU	11,970	11,206	-3.2%
Combo	49,973	49,229	-0.7%
Other Arterial			
PV	322,288	324,467	0.3%
SU	20,176	18,922	-3.2%
Combo	31,771	33,023	2.0%
Other Rural			
PV	335,206	327,748	-1.1%
SU	19,286	18,059	-3.2%
Combo	16,287	16,281	0.0%
Total Rural			
PV	838,772	837,428	-0.1%
SU	51,431	48,188	-3.2%
Combo	98,031	98,532	0.3%
Urban			
Interstate			
PV	423,699	427,395	0.4%
SU	16,752	14,485	-7.0%
Combo	35,663	35,812	0.2%
Other Urban			
PV	1,403,376	1,415,087	0.4%
SU	58,672	48,001	-9.5%
Combo	50,131	41,567	-8.9%
Total Urban			
PV	1,827,075	1,842,482	0.4%
SU	75,423	62,486	-9.0%
Combo	85,794	77,379	-5.0%
Total			
PV	**2,665,848**	**2,679,910**	**0.3%**
SU	**126,855**	**110,674**	**-6.6%**
Combo	**183,826**	**175,911**	**-2.2%**

The procedures used to develop estimates of travel by vehicle type have been significantly revised; the data available do not support direct comparisons prior to 2007.

Data do not include Puerto Rico.

PV = Passenger Vehicles (including buses, motorcycles and two-axle, four-tire vehicles); SU = Single-Unit Trucks (6 or more tires); Combo = Combination Trucks (trailers and semitrailers).

Source: Highway Statistics, various years, Table VM-1.

Passenger vehicle travel grew at an average annual rate of 0.3 percent from 2008 to 2010. Over the same period, combination truck traffic declined by 2.2 percent per year, and single-unit truck traffic declined by 6.6 percent per year. The decrease in combination truck traffic occurred mostly in urban areas; single-unit truck traffic decreased in both rural and urban areas, but the change was more pronounced in urban areas. Direct comparisons over a longer time period cannot be made due to significant revisions to the vehicle distribution estimation methodology implemented in 2007.

Toll Roads, HOT Lanes, and/or HOV Lanes

The best source of information regarding toll roads in the Nation is the Toll Facilities Report (FHWA-PL-11-032, July 2011) published by the Office of Highway Policy Information. The report contains selected information on toll facilities in the United States that has been provided to FHWA by the States and/or various toll authorities regarding toll facilities in operation, financed, or under construction as of July 2011. The report is based on voluntary responses received biennially. Since data submission is voluntary, the report may not contain complete information as to toll roads in the Nation. As of 2011, there were 3,088 miles of Interstate toll roads and 1,992 miles of non-Interstate toll roads reported.

The HPMS database contains very limited data on miles of HOT lanes and HOV lanes. The data available in the HPMS indicate that there were 1,065 miles of HOV lanes. However, since information regarding HOT/HOV lanes may be incomplete, this number may not accurately reflect actual mileage.

Federal-Aid Highways

The term "Federal-aid highways" includes roads that are generally eligible for Federal funding assistance under current law, which includes public roads that are not functionally classified as rural minor collector, rural local, or urban local. As shown in *Exhibit 2-10*, the extent of Federal-aid highways totaled slightly more than 1.0 million miles in 2010. Federal-aid highways included more than 2.4 million lane miles and carried more than 2.5 trillion VMT in 2010. VMT on Federal-aid highways grew at an average annual rate of 0.8 percent from 2000 to 2010. Lane miles on Federal-Aid Highways also grew at an annual average rate of 0.8 percent during the same period.

Federal-aid highway mileage made up 24.7 percent of the total highway miles on the Nation's roadways in 2010. The number of lane miles on Federal-aid highways was approximately 28.4 percent of the Nation's total lane mileage. The VMT carried on Federal-aid highways made up 84.6 percent of the VMT for the Nation.

While the system characteristics information presented in this chapter is available for all functional classes, some data pertaining to system conditions and performance presented in other chapters are not available in the HPMS for roads classified as rural minor collector, rural local, or urban local. Thus, some data presented in other chapters may reflect only Federal-aid highways.

Exhibit 2-10 **Federal-Aid Highway Miles, Lane Miles, and VMT, 2000–2010**

	2000	2002	2004	2006	2008	2010	Annual Rate of Change 2010/2000
Highway Miles	959,339	959,125	971,036	984,093	994,358	1,007,777	0.5%
Lane Miles	2,271,990	2,282,024	2,319,417	2,364,514	2,388,809	2,451,140	0.8%
VMT (millions)	2,342,690	2,430,698	2,531,629	2,573,956	2,534,490	2,525,455	0.8%

Source: Highway Performance Monitoring System.

National Highway System

With the Interstate System essentially complete, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) revised the Federal-aid highway program for the post-Interstate System era. The legislation authorized designation of an NHS that would prioritize Federal resources to roads most important for interstate travel, economic expansion, and national defense; that connect with other modes of transportation; and that are essential to the Nation's role in the international marketplace.

The NHS was designed to be a dynamic system capable of changing in response to future travel and trade demands. The U.S. Department of Transportation may approve modifications to the NHS without congressional approval. States must cooperate with local and regional officials in proposing modifications. In metropolitan areas, local and regional officials must act through metropolitan planning organizations and the State transportation department when proposing modifications. A number of such modifications are proposed and approved each year.

The NHS has five components. The first, the Interstate System, is the core of the NHS and includes the most traveled routes. The second component includes other principal arterials deemed most important for commerce and trade. The third is the Strategic Highway Network (STRAHNET), which consists of highways important to military mobilization. The fourth is the system of STRAHNET connectors that provides access between major military installations and routes that are part of STRAHNET. The final component consists of intermodal connectors, which were not included in the National Highway System Designation Act of 1995 but are eligible for NHS funds. These roads provide access between major intermodal passenger and freight facilities and the other four subsystems that make up the NHS.

Q&A

Which governmental entities own the mileage that makes up the National Highway System?

Approximately 96.9 percent of NHS mileage was State-owned in 2010. Only 3.0 percent was locally owned and the Federal government owned the remaining 0.1 percent. The NHS is concentrated on higher functional systems, which tend to have higher shares of State-owned mileage.

The Moving Ahead for Progress in the 21st Century Act of 2012 (MAP-21) modified the scope of the NHS to include some additional principal arterial and related connector mileage not previously designated as part of the NHS. The statistics presented in this chapter pertain to the NHS as it existed in 2010.

Q&A

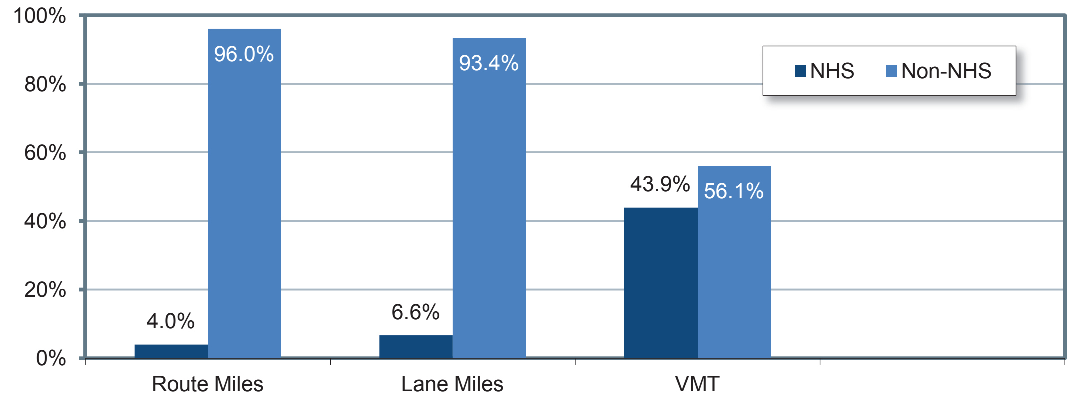
What changes will the National Highway System experience under MAP-21?

The revised NHS criteria in MAP-21 would add to the NHS most of the principal arterial mileage that is not currently part of the system. If all principal arterial mileage were added, this would expand the length of the NHS by 37.7 percent, to over 224,300 miles from 162,876 miles prior to MAP-21. While this estimate includes some principal arterial mileage that may not ultimately be included in the NHS, it excludes additional intermodal connector mileage that may be added. This estimate of the extent of the future NHS is used in Part II of this report as the basis for 20-year NHS investment/performance projections.

Combining the current NHS with all other principal arterial mileage would cover 5.5 percent of the Nation's route miles, 8.9 percent of lane miles, and 55.2 percent of VMT.

Exhibit 2-11 summarizes NHS route miles, lane miles, and VMT for the NHS components. The NHS is overwhelmingly concentrated on higher functional systems. All Interstate System highways are part of the NHS, as are 96.0 percent of rural other freeways and expressways, 84.3 percent of urban other freeways and expressways, 79.9 percent of rural other principal arterials, and 39.6 percent of urban other principal arterials. The share of minor arterials, collectors, and local roads on the NHS is relatively small. As of 2010, there were 162,698 route miles on the NHS, excluding any sections not yet open to traffic. While only 4.0 percent of the Nation's total route mileage and 6.7 percent of the total lane miles were on the NHS, these roads carried 44.0 percent of VMT in 2010.

Exhibit 2-11 Highway Route Miles, Lane Miles, and VMT on the NHS Compared With All Roads, by Functional System, 2010



	Route Miles		Lane Miles		VMT (Millions)	
	Total on NHS	Percent of Functional System on NHS	Total on NHS	Percent of Functional System on NHS	Total on NHS	Percent of Functional System on NHS
Rural NHS						
Interstate	30,244	100.0%	123,653	100.0%	244,484	100.0%
Other Freeway and Expressway*	4,090	96.0%	15,074	95.8%	18,906	96.4%
Other Principal Arterial*	72,838	79.9%	195,336	82.0%	171,226	83.2%
Minor Arterial	3,124	2.3%	7,311	2.6%	5,338	3.5%
Major Collector	1,159	0.3%	2,619	0.3%	1,603	0.9%
Minor Collector	17	0.0%	33	0.0%	4	0.0%
Local	59	0.0%	197	0.0%	150	0.1%
Subtotal Rural NHS	**111,530**	**3.7%**	**344,223**	**5.6%**	**441,711**	**44.9%**
Urban NHS						
Interstate	16,657	100.0%	92,266	100.0%	477,591	100.0%
Other Freeway and Expressway*	9,575	84.3%	45,503	85.7%	196,079	88.8%
Other Principal Arterial*	22,774	35.0%	85,493	37.2%	180,778	39.6%
Minor Arterial	1,585	1.5%	4,831	1.7%	7,133	1.9%
Major Collector	466	0.4%	1,163	0.5%	1,329	0.8%
Minor Collector	15	0.5%	31	0.4%	6	0.1%
Local	95	0.0%	233	0.0%	160	0.0%
Subtotal Urban NHS	**51,167**	**4.7%**	**229,520**	**9.4%**	**863,074**	**43.5%**
Total NHS	**162,698**	**4.0%**	**573,744**	**6.7%**	**1,304,786**	**44.0%**

** Under MAP-21, most roads on these functional systems will become part of the NHS.*

Source: Highway Performance Monitoring System, December 2010.

Interstate System

With the strong support of President Dwight D. Eisenhower, the Federal-Aid Highway Act of 1956 declared that the completion of the "National System of Interstate and Defense Highways" was essential to the national interest. The Act made a national commitment to the completion of the Interstate System within the Federal–State partnership of the Federal-aid highway program, with the State responsible for construction to approved standards. The Act also resolved the challenging issue of how to pay for construction by establishing the Highway Trust Fund to ensure that revenue from highway user taxes, such as the motor fuels tax, would be dedicated to the Interstate System and other Federal-aid highway and bridge projects.

President Eisenhower wrote in his memoirs that "more than any single action by the government since the end of the war, this one would change the face of America. Its impact on the American economy . . . was beyond calculation." The Dwight D. Eisenhower National System of Interstate and Defense Highways, as it is now called, accelerated interstate and regional commerce, enhanced the country's competitiveness in international markets, increased personal mobility, facilitated military transportation, and accelerated metropolitan development throughout the United States. Although the Interstate System accounted for only 1.2 percent of the Nation's total roadway mileage in 2010, it carried 24.2 percent of all highway travel.

Exhibit 2-12 combines data presented earlier in this section for rural and urban Interstate System highways. From 2000 to 2010, Interstate System miles grew at an average annual rate of 0.1 percent to 47,182. Over this same period, Interstate System lane miles grew by 0.4 percent annually to 217,165, and the traffic carried by the Interstate System grew by 0.9 percent per year to over 0.7 trillion VMT.

Exhibit 2-12 **Interstate Highway Miles, Lane Miles, and VMT, 2000–2010**

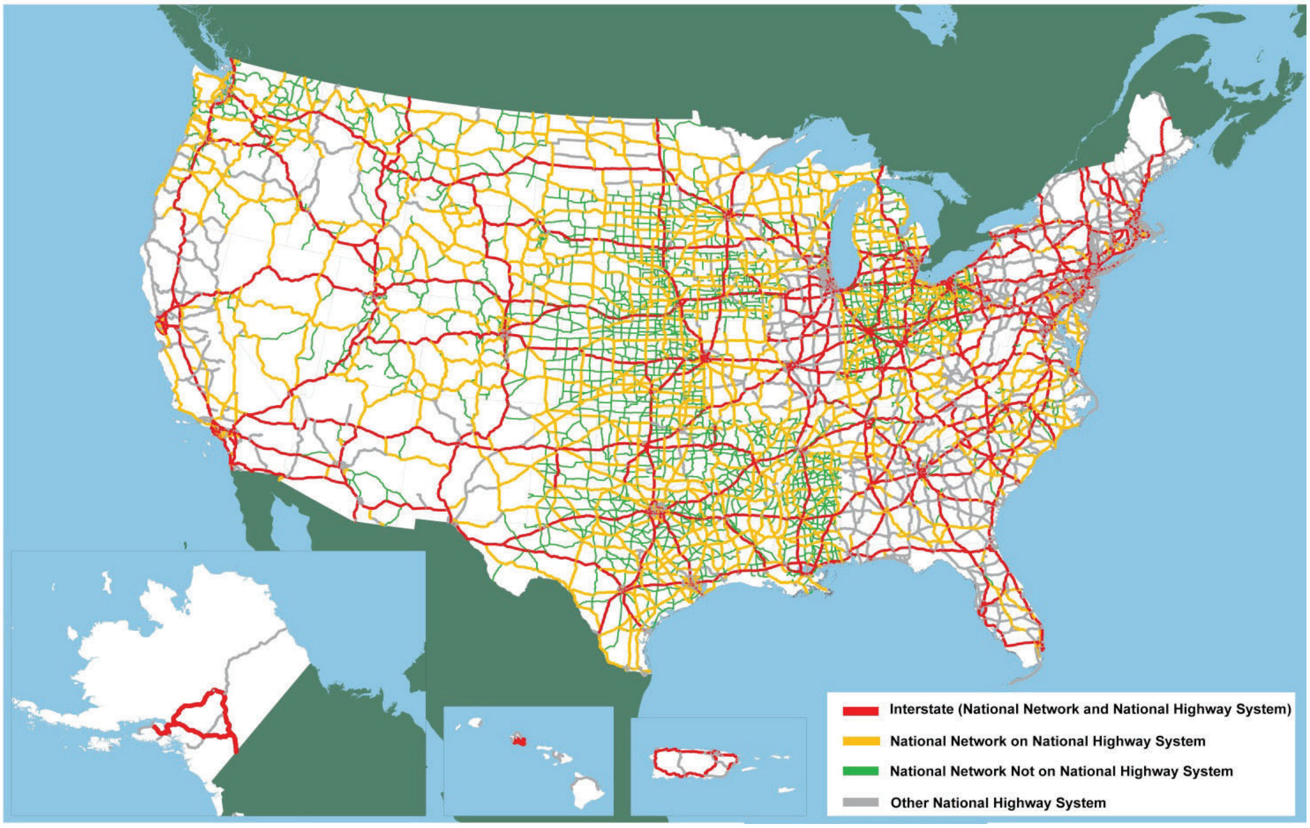
	2000	2002	2004	2006	2008	2010	Annual Rate of Change 2010/2000
Highway Miles	46,675	46,747	46,836	46,892	47,019	47,182	0.1%
Lane Miles	209,647	210,896	212,029	213,542	214,880	217,165	0.4%
VMT(millions)	666,708	693,941	727,163	741,002	725,213	731,095	0.9%

Source: Highway Performance Monitoring System, December 2011.

Highway Freight System

The U.S. freight highway transportation system is, at its fullest extent, composed of all Federal, State, local (county or municipal), and private roads that permit trucks and other commercial vehicles that haul freight. The National Network (shown in *Exhibit 2-13*) is a system composed of 200,000 miles of roadways that is officially designated to accommodate commercial freight-hauling vehicles. The National Network was designated under the Surface Transportation Assistance Act of 1982, which requires States to allow trucks of certain specific sizes and configurations on the "Interstate System and those portions of the Federal-aid Primary System … serving to link principal cities and densely developed portions of the States … utilized extensively by large vehicles for interstate commerce." National Network roadways are required to permit conventional combination trucks that are up to 102 inches wide, and accommodate truck tractors that have a single semi-trailer up to 48 feet in length or have two 28-foot trailers. Most States currently allow conventional combination trucks with single trailers up to 53 feet in length to operate without permits on their portions of the National Network.

Exhibit 2-13 National Network for Conventional Combination Trucks, 2009



Notes: This map should not be interpreted as the official National Network and should not be used for truck size and weight enforcement purposes. The National Network and NHS are approximately 200,000 miles in length, but the National Network includes 65,000 miles of highway beyond the NHS, and the NHS encompasses about 50,000 miles of highways that are not part of the National Network. "Other NHS" refers to NHS mileage that is not included on the National Network. Conventional combination trucks are tractors with one semitrailer up to 48 feet in length or with one 28-foot semitrailer and one 28-foot trailer. Conventional combination trucks can be up to 102 inches wide.

Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, version 2.2, 2009. ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/docs/09factsfigures/figure3_3.htm.

Although there is significant overlap between the National Network and the NHS, they represent two distinct systems. The National Network has not changed significantly since its designation in 1982. Maintaining truck access to ports, industrial activities in central cities, supporting interstate commerce, and regulating the size of trucks are main priorities of the National Network.

Changes under MAP-21

The MAP-21 surface transportation reauthorization bill requires the creation and definition of a National Freight Network, which is intended to include the most important urban, rural, and intercity routes for commercial truck movements. This newly designated network, which does not have a specified roadway mileage, will likely be smaller than National Network or the NHS, and will overlap portions of both previously defined systems, though it will also include mileage that is not part of either the National Network or the NHS. The National Freight Network will consist of (1) a Primary Freight Network designated by the U.S. DOT, (2) the portions of the Interstate Highway System that are not selected to be part of the Primary Freight Network, and (3) Critical Rural Freight Corridors that are designated by the States. The Primary Freight Network will initially include no more than 27,000 centerline miles of existing

roadways, and will be determined based on eight freight-related factors identified in 23 USC 167(d)(1)(B): "(i) the origins and destinations of freight movement in the United States; (ii) the total freight tonnage and the value of freight movement by highways; (iii) the percentage of average annual daily truck traffic in the annual average daily traffic on principal arterials; (iv) the annual average daily truck traffic on principal arterials; (v) land and maritime ports of entry; (vi) access to energy exploration, development, installation, or production areas; (vii) population centers; and (viii) network connectivity." The Critical Rural Freight Corridors will need to meet at least one of the following three criteria: (1) is a rural, principal arterial that has trucks comprising a minimum of 25 percent of total AADT; (2) provides access to energy exploration, development, installation, or production; or (3) connects the primary freight network, a roadway meeting either (1) or (2) above, or an Interstate Highway System corridor to facilities that annually handle more than 50,000 twenty-foot equivalent (TEU) units or 500,000 tons of bulk commodities.

System Resiliency

An important aspect of system reliability (see Chapter 5) is the resiliency of the system. Resiliency measures the ability of the transportation system to minimize service disruptions despite variable and unexpected condition changes, such as extreme weather or a failure of infrastructure. Resiliency impacts both the physical infrastructure and operational solutions to overcome the sudden change. Events which test resiliency are of a low probability but are potentially highly disruptive to operations such as a hurricane, port/terminal closure, or bridge collapse, such as the Washington I-5 bridge collapse in May 2013. Resiliency is a factor of both the physical infrastructure (for example, how well a bridge responds to being hit) and the operations of the infrastructure (for example, how quickly responders are able to precipitate a safe detour and reconstruct the bridge). While the I-5 bridge did not demonstrate structural resilience to the strike of the truck that caused the collapse, Washington DOT used operational strategies to quickly operationalize a detour route, construct a temporary bridge in less than 1 month, and construct a replacement bridge in less than 5 months. System resiliency requires investments in both resilient infrastructure and emergency response plans by State DOTs.

 FHWA002205

Bridge System Characteristics

Bridges are vital components of the Nation's roadway system. Some allow for the unimpeded movement of traffic over barriers created by geographical features such as rivers; others are used in interchanges to facilitate the exchange of traffic between roadways.

The National Bridge Inventory (NBI) contains information detailing physical characteristics, traffic loads, and the evaluation of the condition of each bridge with a length greater than 20 feet (6.1 meters). As of December 2010, the NBI contained records for 604,493 bridges. Data for input to the NBI is collected on a regular basis as set forth in the National Bridge Inspection Standards.

Bridges by Owner

The owner of a particular bridge is responsible for the maintenance and activities required to keep the bridge safe for public use and can be a Federal, State, or local agency. Only 1.3 percent of the bridges in the Nation in 2010 were owned by agencies within the Federal government. The majority of these bridges are owned by the Department of the Interior and the Department of Defense. Among the bridges reported in the NBI, approximately 0.3 percent were coded as owned by private entities or coded with unknown or unclassified ownership.

Which governmental entities owned the bridges on the NHS in 2010?

Q&A

In 2010, approximately 97.5 percent of bridges on the NHS were State owned, 2.2 percent were locally owned, and 0.1 percent were owned by the Federal government. The remainder were privately owned, were owned by railroads, or had an owner that was not recorded.

In 2010, State agencies owned 291,145 bridges, or approximately 48.2 percent of the all bridges, which carried 87.5 percent of the total traffic on the Nation's bridge system. Local agencies owned 303,531 bridges in 2010, or approximately 50.2 percent of all bridges. Local agencies own slightly more bridges than State agencies, but many of them tend to be smaller structures concentrated on lower-volume routes compared to State inventories. These data are summarized in *Exhibit 2-14*.

Between 2000 and 2010, the total number of bridges grew at an average annual rate of 0.3 percent to 604,493 bridges on the Nation's roadways. This increase has been concentrated in State-owned and locally owned bridges. During this same timeframe, the percentage of bridges owned by the Federal government and private entities decreased.

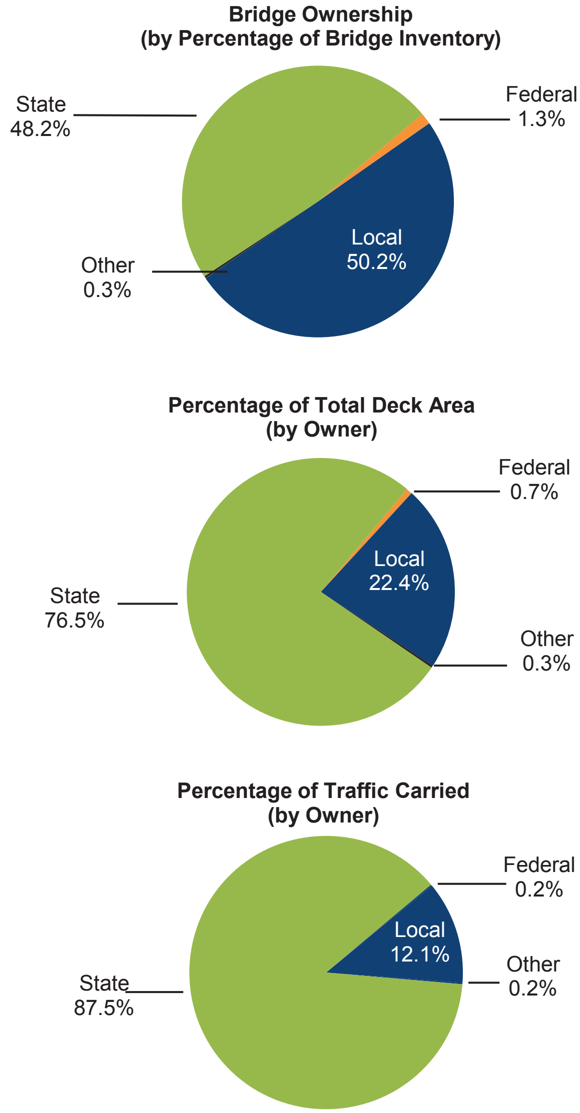
Exhibit 2-14 Bridges by Owner, 2000–2010

Owner	2000	2002	2004	2006	2008	2010	Annual Rate of Change 2010/2000
Federal	8,221	9,371	8,425	8,355	8,383	8,150	-0.1%
State	277,106	280,266	282,552	284,668	289,051	291,145	0.5%
Local	298,889	299,354	300,444	301,912	302,278	303,531	0.2%
Private	2,299	1,502	1,497	1,490	1,427	1,366	-5.1%
Unknown/Unclassified	415	1,214	1,183	1,137	367	301	-3.2%
Total	**586,930**	**591,707**	**594,101**	**597,562**	**601,506**	**604,493**	**0.3%**

Source: National Bridge Inventory as of December 2010.

As shown in *Exhibit 2-15*, despite States owning 48.2 percent of total bridges in 2010, these bridges constituted 76.5 percent of total bridge deck area and carried 87.5 percent of total bridge traffic. In 2010, State agencies owned more than 3 times the bridge deck area of local agencies and carried more than 7 times the traffic of bridges owned by local agencies.

Exhibit 2-15 Bridge Inventory Characteristics for Ownership, Traffic, and Deck Area, 2010



Source: National Bridge Inventory as of December 2010.

Interstate, STRAHNET, and NHS Bridges

Exhibit 2-16 shows that the Interstate system had 55,339 bridges, or 9.2 percent of the total bridges on the road system of the Nation, in 2010. Bridges on the Interstate make up 26.4 percent of the total deck area of bridges on the Nation's roadway system. Interstate bridges carry approximately 44.9 percent of average daily traffic and 58.3 percent of the Nation's Average Daily Truck Travel (ADTT).

The Strategic Highway Network (STRAHNET) system, including Interstate highways and other routes critical to national defense, included 68,529 bridges in 2010. All STRAHNET routes, including STRAHNET connectors, are included as part of the National Highway System (NHS).

As of 2010, the 116,669 bridges on the NHS constituted 19.3 percent of total bridges in the Nation. However, NHS bridges constituted 49.0 percent of total bridge deck area, carried 70.7 percent of total bridge traffic, and carried 81.0 percent of bridge truck traffic. As referenced earlier in this chapter, the NHS includes the entire Interstate System as well as additional critical routes.

Exhibit 2-16 Interstate, STRAHNET, and NHS Bridges Weighted by Numbers, ADT, and Deck Area, 2010

Federal System*	Number of Bridges	Percent by Number of Bridges	Deck Area Sq Meters (1000)	Percent of Total Deck Area	ADT (1000)	Percent of Total ADT	Truck ADT (1000)	Percent of Total Truck ADT
Interstate System	55,339	9.2%	92,668	26.4%	1,992,392	44.9%	240,911	58.3%
STRAHNET	68,529	11.3%	108,690	30.9%	2,223,702	50.1%	262,512	63.6%
NHS	116,669	19.3%	172,167	49.0%	3,138,800	70.7%	334,973	81.1%
Federal-Aid Hwy	319,108	52.8%	293,485	83.5%	4,235,908	95.4%	402,992	97.6%
All Systems	604,493	100%	351,470	100%	4,438,757	100%	413,073	100%

** The NHS includes all of STRAHNET; STRAHNET includes the entire Interstate System.*

Source: National Bridge Inventory as of December 2010.

What is meant by "deck area" and how is the information about deck area used?

Q&A

The deck area of a bridge is the width of the roadway surface of a bridge multiplied by the length of the bridge. Pedestrian walkways and bike paths may be included in the roadway width.

Prior to MAP-21, the deck area of bridge was an essential calculation for use in the apportionment process of Highway Bridge Program funds.

The deck area of a bridge is an indicator as to the size of a bridge. Bridges with large deck areas are usually associated with having multiple lanes and large traffic volumes, and/or are over major geographical features requiring a great distance to span. The deck area of a bridge may be used to aid in determining the level of investment as part of a risk based prioritization process.

Example:

Bridge "A" carries two lanes of traffic on a local road that crosses a small stream. The bridge length is 30 feet and the roadway width is 26 feet for a total deck area of 780 square feet. The bridge has been rated as deficient.

Bridge "B" carries four lanes of traffic on the Interstate and crosses over a major river. The length of the bridge is 600 feet and the roadway width is 60 feet for a total deck area of 36,000 square feet. It has also been rated as deficient.

In a simple count reflecting deficient bridges both are equal in value, however, when deck area is considered, the difference between a 36,000 square foot bridge and a 780 square foot bridge indicates there is a potentially vast difference in the funding required to rehabilitate the Interstate bridge versus the bridge on the local road.

Bridges by Roadway Functional Classification

The NBI maintains the highway functional classification of the road on which a bridge is located. The NBI follows the hierarchy used for highway systems as previously described in this chapter. The number of bridges by roadway functional classification is summarized and compared with previous years in *Exhibit 2-17*.

As noted earlier in this chapter, changes in urban area boundaries resulting from the 2000 Census led to reductions in the number of rural bridges and an increase in urban bridges. As shown in *Exhibit 2-17*, the largest change in the number of bridges on a single functional class highway between 2000 and 2010 occurred on urban collectors with an annual increase of 3.1 percent.

Exhibit 2-18 shows the relationship between bridges among various rural and urban functional classes. In 2010, there were approximately 2.8 bridges on rural roadways for every bridge on the urban system. However, urban bridges carried more than 3.2 times the ADT of rural bridges and constituted slightly less than 1.3 times the deck area of rural bridges.

The greatest number of bridges on any functional system, rural or urban, is on rural local. In 2010 there were a total of 205,609 rural local functional class bridges constituting 34.0 percent of all bridges. Rural functional class bridges alone outnumber bridges in urban areas on all functional classifications. However, rural local bridges only account for 9.5 percent of the total bridge deck area in the Nation and carry only 1.4 percent of total bridge ADT.

The 30,116 urban Interstate bridges constitute only 5.0 percent of the Nation's bridges. However, urban Interstate bridges have the greatest share of deck area among the functional classes at 19.4 percent and carry the greatest share of ADT at 35.8 percent. Many urban Interstate bridges are part of interchanges and carry significant volumes of traffic.

Exhibit 2-17 Number of Bridges by Functional System, 2000–2010

Functional System	2000	2002	2004	2006	2008	2010	Annual Rate of Change 2010/2000
Rural							
Interstate	27,797	27,310	27,648	26,633	25,997	25,223	-1.0%
Other Principal Arterials	35,417	35,215	36,258	35,766	35,594	36,084	0.2%
Minor Arterial	39,377	39,571	40,197	39,521	39,079	39,048	-0.1%
Major Collector	95,559	94,766	94,079	93,609	93,118	93,059	-0.3%
Minor Collector	47,797	49,309	49,391	48,639	48,242	47,866	0.0%
Local	209,410	209,358	208,641	207,130	205,959	205,609	-0.2%
Subtotal Rural	455,357	455,529	456,214	451,298	447,989	446,889	-0.2%
Urban							
Interstate	27,882	27,924	27,667	28,637	29,629	30,116	0.8%
Other Expressways	16,011	16,843	17,112	17,988	19,168	19,791	2.1%
Other Principal Arterials	24,146	24,301	24,529	26,051	26,934	27,373	1.3%
Minor Arterial	23,020	24,510	24,802	26,239	27,561	28,103	2.0%
Collectors	15,036	15,169	15,548	17,618	18,932	20,311	3.1%
Local	25,683	26,592	27,940	29,508	31,183	31,877	2.2%
Subtotal Urban	131,778	135,339	137,598	146,041	153,407	157,571	1.8%
Unclassified	**600**	**375**	**288**	**222**	**110**	**33**	
Total	**587,735**	**591,243**	**594,100**	**597,561**	**601,506**	**604,493**	**0.3%**

Source: National Bridge Inventory as of December 2010.

Exhibit 2-18 Bridges by Functional System Weighted by Numbers, ADT, and Deck Area, 2010

Functional System	Number of Bridges	Percent by Total Number	Deck Area Sq Meters (1000)	Percent of Total Deck Area	ADT (1,000)	Percent of Total ADT
Rural						
Interstate	25,223	4.2%	24,656	7.0%	404,151	9.1%
Other Principal Arterial	36,084	6.0%	31,015	8.8%	259,639	5.8%
Minor Arterial	39,048	6.5%	21,576	6.1%	144,499	3.3%
Major Collector	93,059	15.4%	32,591	9.3%	142,267	3.2%
Minor Collector	47,866	7.9%	11,302	3.2%	34,828	0.8%
Local	205,609	34.0%	33,529	9.5%	63,373	1.4%
Subtotal Rural	**446,889**	**73.9%**	**154,668**	**44.0%**	**1,048,757**	**23.6%**
Urban						
Interstate	30,116	5.0%	68,012	19.4%	1,588,241	35.8%
Other Freeways & Expressways	19,791	3.3%	37,296	10.6%	720,988	16.2%
Other Principal Arterial	27,373	4.5%	39,333	11.2%	525,255	11.8%
Minor Arterial	28,103	4.6%	26,354	7.5%	327,646	7.4%
Collector	20,311	3.4%	12,652	3.6%	123,222	2.8%
Local	31,877	5.3%	13,124	3.7%	104,495	2.4%
Subtotal Urban	**157,571**	**26.1%**	**196,772**	**56.0%**	**3,389,846**	**76.4%**
Unclassified	**33**	**0.0%**	**30**	**0.0%**	**154**	**0.0%**
Total	**604,493**	**100.0%**	**351,470**	**100.0%**	**4,438,757**	**100.0%**

Source: National Bridge Inventory as of December 2010.

In 2010, there were 2.8 Interstate bridges on rural roadways for every Interstate bridge in urban areas. While there were fewer bridges in urban areas compared to rural areas, the volume of traffic carried by urban Interstate bridges was more than 3.9 times the ADT carried by rural Interstate bridges in 2010. As reported in the 2010 Conditions & Performance Report, the ADT carried on urban Interstate bridges in 2010 was more than 1.5 times the ADT carried on all rural bridges combined.

Bridges by Traffic Volume

As shown in *Exhibit 2-19*, many bridges carried relatively low volumes of traffic on a typical day in 2010. Approximately 319,196 bridges, or 52.8 percent of the total bridges in the Nation, had an ADT of 1,000 or less. An additional 180,371 bridges, or 29.8 percent of all bridges, had an ADT between 1,001 and 10,000. Only 17,793 of the Nation's bridges, or 2.9 percent, had an ADT higher than 50,000. The remaining 87,133 bridges, or 14.4 percent, had an ADT between 10,001 and 50,000.

Of the bridges which have an ADT higher than 50,000, approximately 2.0 percent, or 12,147 bridges, are on the Interstate system. Interstate bridges in urban areas account for slightly more than 93.6 percent of these bridges. When all bridges that carry the highest category of ADT are considered, the number of bridges in urban areas outnumber rural bridges by more than 100 to 1.

Exhibit 2-19 **Number of Bridges by Functional Class and ADT Group, 2010**

Functional System	Average Daily Traffic Category			
	< 1,000 ADT	1,001 to 10,000 ADT	10,001 to 50,000 ADT	> 50,000 ADT
Rural				
Interstate	394	10,078	13,979	772
Other Principal Arterial	1,342	27,742	6,879	121
Minor Arterial	7,616	29,131	2,287	14
Major Collector	54,334	37,589	1,133	3
Minor Collector	38,980	8,708	173	5
Local	195,682	9,429	481	17
Subtotal Rural	**298,348**	**122,677**	**24,932**	**932**
Urban				
Interstate	364	4,044	14,333	11,375
Other Freeways & Expressways	243	4,113	11,328	4,107
Other Principal Arterial	356	7,700	18,272	1,045
Minor Arterial	1,140	14,213	12,571	179
Collector	3,050	13,850	3,353	58
Local	15,670	13,771	2,339	97
Subtotal Urban	**20,823**	**57,691**	**62,196**	**16,861**
Unclassified	**25**	**3**	**5**	**0**
Total	**319,196**	**180,371**	**87,133**	**17,793**

Source: National Bridge Inventory as of December 2010.

Transit System Characteristics

System History

The first transit systems in the United States date to the late 19th century. These were privately owned, for-profit businesses that were instrumental in defining the urban communities of that time. By the postwar period, competition from the private automobile was making it impossible for transit businesses to operate at a profit. As they started to fail, local, State, and national government leaders began to realize the importance of sustaining transit services. In 1964, Congress passed the Urban Mass Transportation Act, which established the agency now known as the Federal Transit Administration (FTA) to administer Federal funding for transit systems. The Act also changed the character of the industry by specifying that Federal funds for transit were to be given to public agencies rather than private firms; this accelerated the transition from private to public ownership and operation of transit systems. The Act also required local governments to contribute matching funds in order to receive Federal aid for transit services, setting the stage for the multilevel governmental partnerships that continue to characterize the transit industry today.

State government involvement in the provision of transit services is usually through financial support and performance oversight. However, some States have undertaken outright ownership and operation of transit services. Connecticut, Georgia, Louisiana, Maryland, Ohio, and Washington all own and operate transit systems directly, as does Puerto Rico. Michigan and Pennsylvania contract for transit services.

Some Transit Vocabulary

Modal network refers to a system of routes and stops served by one type of transit technology; this could be a bus network, a light rail network, a ferry network, or a demand response system. Transit operators often maintain several different modal networks, most often motor bus systems augmented with demand response service.

Articulated bus is an extra-long (54- to 60-foot) bus with two connected passenger compartments. The rear body section is connected to the main body by a joint mechanism that allows the vehicles to bend when in operation for sharp turns and curves and yet have a continuous interior.

Automated Guideway Systems are driverless, rubber-tire vehicles usually running alone or in pairs on a single broad concrete rail, typical of most airport trains, although airport trains are not considered transit service by FTA.

Demand response service usually consists of passenger cars, vans, or small buses operating in response to calls from passengers or their agents to the transit operator, who then dispatches a vehicle to pick up the passengers and transport them to their destinations. The vehicles do not operate over a fixed route or on a fixed schedule, except on a temporary basis to satisfy a special need. A vehicle may be dispatched to pick up several passengers at different pickup points before taking them to their respective destinations.

Públicos or "public cars" are typically 17-passenger vans that serve towns throughout Puerto Rico, stopping in each community's main plaza or at a destination requested by a passenger. They generally operate without a set schedule, primarily during the day; the public service commission fixes routes and fares. San Juan-based Público companies include Blue Line for trips to Aguadilla and the northwest coast, Choferes Unidos de Ponce for Ponce, Línea Caborrojeña for Cabo Rojo and the southwest coast, Línea Boricua for the interior and the southwest, Línea Sultana for Mayagüez and the west coast, and Terminal de Transportación Pública for Fajardo and the east.

Jitneys are generally small-capacity vehicles that follow a rough service route but can go slightly out of their way to pick up and drop off passengers. In many U.S. cities (e.g., Pittsburgh and Detroit), the term "jitney" refers to an unlicensed taxicab. In some U.S. jurisdictions, the limit to a jitney is seven passengers.

Cutaways are vehicles comprising a bus body mounted on the chassis of a van or light-duty truck. The original van or light-duty truck chassis may be reinforced or extended. Cutaways typically seat 15 or more passengers and may accommodate some standing passengers.

Revenue service is the time when a vehicle is actively providing service to the general public and either is carrying passengers or is available to them. Revenue from fares is not necessary because vehicles are considered to be in revenue service even when the ride is free.

In 1962, the U.S. Congress passed legislation that required the formation of metropolitan planning organizations (MPOs) for urbanized areas with populations greater than 50,000. MPOs are composed of State and local officials who work to address the transportation planning needs of an urbanized area at a regional level. Twenty-nine years later, the Intermodal Surface Transportation Efficiency Act of 1991 made MPO coordination an essential prerequisite for Federal funding of many transit projects.

State and local transit agencies have evolved into a number of different institutional models. A transit provider may be a unit of a regional transportation agency; may be operated directly by the State, county, or city government; or may be an independent agency with an elected or appointed Board of Governors. Transit operators can provide service directly with their own equipment or they may purchase transit services through an agreement with a contractor. All public transit services must be open to the general public without discrimination and meet the accessibility requirements of the Americans with Disabilities Act of 1990 (ADA).

System Infrastructure

Urban Transit Agencies

In 2010, there were 728 agencies in urbanized areas that were required to submit data to the National Transit Database (NTD), of which 709 were public agencies, including eight State Departments of Transportation (DOTs). The remaining 19 agencies were either private operators or independent agencies (e.g., nonprofit organizations). One hundred thirty-one agencies received either a reporting exemption for operating nine or fewer vehicles or a temporary reporting waiver; 611 agencies reported providing service on 1,240 separate modal networks; all but 148 agencies operated more than one mode. In 2010, there were an additional 1,599 transit operators serving rural areas. Not all transit providers are included in these counts because those that do not receive grant funds from FTA are not required to report to NTD. Some, but not all, agencies report anyway, as this can help their region receive Federal transit funding.

The Nation's motor bus and demand response systems are much more extensive than the Nation's rail transit system. In 2010, there were 612 motor bus systems and 587 demand-response systems (not including demand-response taxi) in urban areas, compared with 18 heavy rail systems, 30 commuter rail systems, and 33 light rail systems (some of which are not yet in service). While motor bus and demand response systems were found in every major urbanized area in the United States, 44 urbanized areas were served by at least one of the three primary rail modes, including 20 by commuter rail, 30 by light rail, and 14 by heavy rail (rail systems are listed in *Exhibit 2-20*). In addition to these modes, there were 70 publicly operated transit vanpool systems, 20 ferryboat systems, five trolleybus systems, three automated guideway systems, three inclined plane systems, and one cable car system operating in urbanized areas of the United States and its territories.

The transit statistics presented in this report also include the San Francisco Cable Car, the Seattle Monorail, the Roosevelt Island Aerial Tramway in New York, and the Alaska Railroad (which is a long-distance passenger rail system included as public transportation by statutory exemption).

Urbanized Areas with Population over 1 Million in 2010 Census

UZA Rank	UZA Name	2010 Population	2011 Unlinked Transit Trips
1	New York-Newark, NY-NJ-CT	18,351,295	4,017,665,768
2	Los Angeles-Long Beach-Anaheim, CA	12,150,996	661,822,454
3	Chicago, IL-IN	8,608,208	644,479,067
4	Miami, FL	5,502,379	158,711,484
5	Philadelphia, PA-NJ-DE-MD	5,441,567	403,855,701
6	Dallas-Fort Worth-Arlington, TX	5,121,892	71,341,858
7	Houston, TX	4,944,332	81,090,736
8	Washington, DC-VA-MD	4,586,770	487,325,732
9	Atlanta, GA	4,515,419	149,556,097
10	Boston, MA-NH-RI	4,181,019	389,568,759
11	Detroit, MI	3,734,090	49,824,000
12	Phoenix-Mesa, AZ	3,629,114	68,018,113
13	San Francisco-Oakland, CA	3,281,212	388,347,627
14	Seattle, WA	3,059,393	187,098,251
15	San Diego, CA	2,956,746	98,128,677
16	Minneapolis-St. Paul, MN-WI	2,650,890	93,892,746
17	Tampa-St. Petersburg, FL	2,441,770	29,116,395
18	Denver-Aurora, CO	2,374,203	89,614,960
19	Baltimore, MD	2,203,663	98,303,955
20	St. Louis, MO-IL	2,150,706	45,258,440
21	San Juan, PR	2,148,346	46,721,752
22	Riverside-San Bernardino, CA	1,932,666	18,495,303
23	Las Vegas-Henderson, NV	1,886,011	56,686,089
24	Portland, OR-WA	1,849,898	111,985,241
25	Cleveland, OH	1,780,673	47,764,261
26	San Antonio, TX	1,758,210	45,493,533
27	Pittsburgh, PA	1,733,853	65,501,247
28	Sacramento, CA	1,723,634	28,712,623
29	San Jose, CA	1,664,496	47,349,903
30	Cincinnati, OH-KY-IN	1,624,827	22,819,990
31	Kansas City, MO-KS	1,519,417	16,766,058
32	Orlando, FL	1,510,516	21,995,359
33	Indianapolis, IN	1,487,483	9,512,303
34	Virginia Beach, VA	1,439,666	16,654,615
35	Milwaukee, WI	1,376,476	46,489,545
36	Columbus, OH	1,368,035	19,049,187
37	Austin, TX	1,362,416	34,740,271
38	Charlotte, NC-SC	1,249,442	27,028,511
39	Providence, RI-MA	1,190,956	21,205,831
40	Jacksonville, FL	1,065,219	12,599,527
41	Memphis, TN-MS-AR	1,060,061	10,616,855
42	Salt Lake City-West Valley City, UT	1,021,243	30,566,260

Exhibit 2-20 Rail Modes Serving Urbanized Areas

Mode: Heavy Rail		
Rail System Name	**UZA Name**	**Vehicles**
MTA New York City Transit (NYCT)	New York-Newark, NY-NJ-CT	5,354
Chicago Transit Authority (CTA)	Chicago, IL-IN	980
Washington Metropolitan Area Transit Authority (WMATA)	Washington, DC-VA-MD	850
San Francisco Bay Area Rapid Transit District (BART)	San Francisco-Oakland, CA	534
Massachusetts Bay Transportation Authority (MBTA)	Boston, MA-NH-RI	342
Southeastern Pennsylvania Transportation Authority (SEPTA)	Philadelphia, PA-NJ-DE-MD	284
Port Authority Trans-Hudson Corporation (PATH)	New York-Newark, NY-NJ-CT	266
Metropolitan Atlanta Rapid Transit Authority (MARTA)	Atlanta, GA	188
Miami-Dade Transit (MDT)	Miami, FL	84
Port Authority Transit Corporation (PATCO)	Philadelphia, PA-NJ-DE-MD	84
Los Angeles County Metropolitan Transportation Authority (LACMTA)	Los Angeles-Long Beach-Santa Ana, CA	70
Maryland Transit Administration (MTA)	Baltimore, MD	54
Staten Island Rapid Transit Operating Authority (SIRTOA)	New York-Newark, NY-NJ-CT	46
Puerto Rico Highway and Transportation Authority (PRHTA)	San Juan, PR	40
The Greater Cleveland Regional Transit Authority (GCRTA)	Cleveland, OH	22
Santa Clara Valley Transportation Authority (VTA)	San Jose, CA	
City and County of Honolulu Department of Transportation Services (DTS)	Honolulu, HI	
Mode: Commuter Rail		
Rail System Name	**UZA Name**	**Vehicles**
New Jersey Transit Corporation (NJ TRANSIT)	New York-Newark, NY-NJ-CT	1,291
Metro-North Commuter Railroad Company (MTA-MNCR)	New York-Newark, NY-NJ-CT	1,075
Northeast Illinois Regional Commuter Railroad Corporation (Metra)	Chicago, IL-IN	1,057
MTA Long Island Rail Road (MTA LIRR)	New York-Newark, NY-NJ-CT	1,014
Massachusetts Bay Transportation Authority (MBTA)	Boston, MA-NH-RI	418
Southeastern Pennsylvania Transportation Authority (SEPTA)	Philadelphia, PA-NJ-DE-MD	325
Southern California Regional Rail Authority (Metrolink)	Los Angeles-Long Beach-Santa Ana, CA	169
Maryland Transit Administration (MTA)	Baltimore, MD	132
Peninsula Corridor Joint Powers Board (PCJPB)	San Francisco-Oakland, CA	95
Virginia Railway Express (VRE)	Washington, DC-VA-MD	78
Northern Indiana Commuter Transportation District (NICTD)	Chicago, IL-IN	66
Central Puget Sound Regional Transit Authority (ST)	Seattle, WA	56
Trinity Railway Express	Dallas-Fort Worth-Arlington, TX	36
South Florida Regional Transportation Authority (TRI-Rail)	Miami, FL	34
Utah Transit Authority (UTA)	Salt Lake City, UT	34
Connecticut Department of Transportation (CDOT)	Hartford, CT	28
North County Transit District (NCTD)	San Diego, CA	26
Rio Metro Regional Transit District (RMRTD)	Albuquerque, NM	25
Metro Transit	Minneapolis-St. Paul, MN	23
Altamont Commuter Express (ACE)	Stockton, CA	21
Pennsylvania Department of Transportation (PENNDOT)	Philadelphia, PA-NJ-DE-MD	20
Northern New England Passenger Rail Authority (NNEPRA)	Boston, MA-NH-RI	14
Regional Transportation Authority (RTA)	Nashville-Davidson, TN	7
Tri-County Metropolitan Transportation District of Oregon (TriMet)	Portland, OR-WA	4
Capital Metropolitan Transportation Authority (CMTA)	Austin, TX	4

Exhibit 2-20 Rail Modes Serving Urbanized Areas

Mode: Light Rail		
Rail System Name	**UZA Name**	**Vehicles**
Massachusetts Bay Transportation Authority (MBTA)	Boston, MA-NH-RI	156
San Francisco Municipal Railway (MUNI)	San Francisco-Oakland, CA	139
Southeastern Pennsylvania Transportation Authority (SEPTA)	Philadelphia, PA-NJ-DE-MD	124
Los Angeles County Metropolitan Transportation Authority (LACMTA)	Los Angeles-Long Beach-Santa Ana, CA	118
Tri-County Metropolitan Transportation District of Oregon (TriMet)	Portland, OR-WA	110
Denver Regional Transportation District (RTD)	Denver-Aurora, CO	104
San Diego Metropolitan Transit System (MTS)	San Diego, CA	93
Dallas Area Rapid Transit (DART)	Dallas-Fort Worth-Arlington, TX	76
New Jersey Transit Corporation (NJ TRANSIT)	New York-Newark, NY-NJ-CT	73
Sacramento Regional Transit District (Sacramento RT)	Sacramento, CA	56
Port Authority of Allegheny County (Port Authority)	Pittsburgh, PA	51
Bi-State Development Agency (METRO)	St. Louis, MO-IL	50
Santa Clara Valley Transportation Authority (VTA)	San Jose, CA	47
Utah Transit Authority (UTA)	Salt Lake City, UT	43
Maryland Transit Administration (MTA)	Baltimore, MD	38
Valley Metro Rail, Inc. (VMR)	Phoenix-Mesa, AZ	32
Metro Transit	Minneapolis-St. Paul, MN	27
Central Puget Sound Regional Transit Authority (ST)	Seattle, WA	26
Niagara Frontier Transportation Authority (NFT Metro)	Buffalo, NY	23
New Orleans Regional Transit Authority (NORTA)	New Orleans, LA	21
The Greater Cleveland Regional Transit Authority (GCRTA)	Cleveland, OH	17
Metropolitan Transit Authority of Harris County, Texas (Metro)	Houston, TX	17
Charlotte Area Transit System (CATS)	Charlotte, NC-SC	16
Memphis Area Transit Authority (MATA)	Memphis, TN-MS-AR	12
North County Transit District (NCTD)	San Diego, CA	6
Hillsborough Area Regional Transit Authority (HART)	Tampa-St. Petersburg, FL	4
Island Transit (IT)*	Galveston, TX	4
Central Arkansas Transit Authority (CATA)	Little Rock, AR	3
Kenosha Transit (KT)	Kenosha, WI	3
Central Puget Sound Regional Transit Authority (ST)	Seattle, WA	2
King County Department of Transportation (King County Metro)	Seattle, WA	2

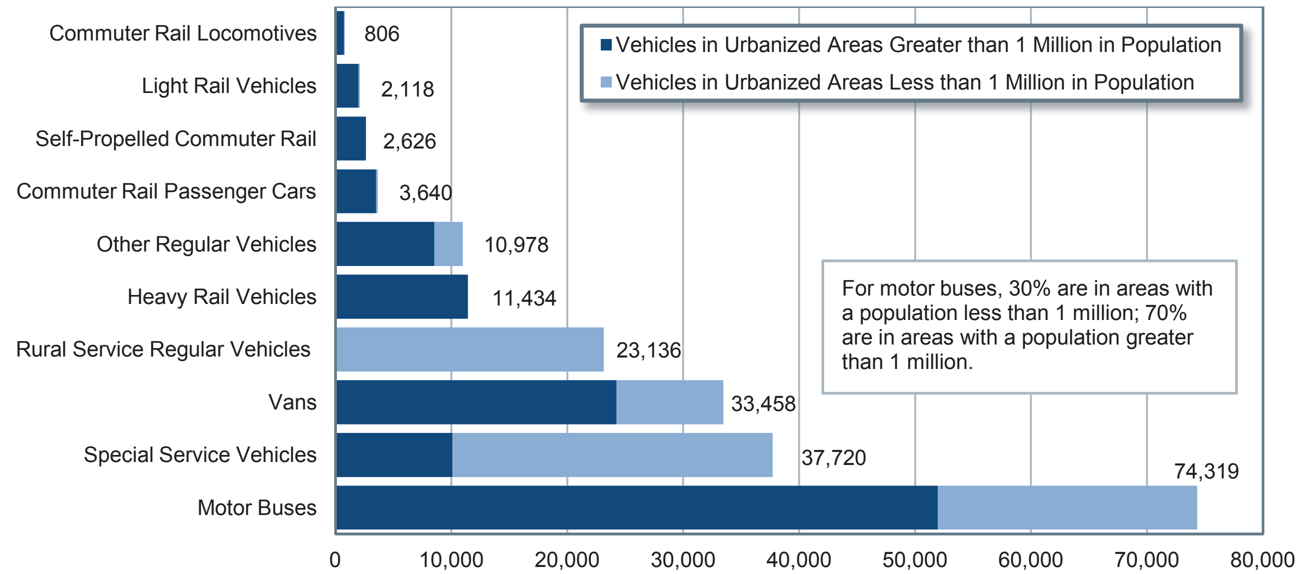
**Island Transit (IT) was not operating in 2010.*

Source: National Transit Database.

Transit Fleet

Exhibit 2-21 provides an overview of the Nation's 200,235 transit vehicles in 2010 by type of vehicle and size of urbanized area. Although some types of vehicles are specific to certain modes, many vehicles—particularly small buses and vans—are used by several different transit modes. For example, vans may be used to provide vanpool, demand response, Público, or motor bus services.

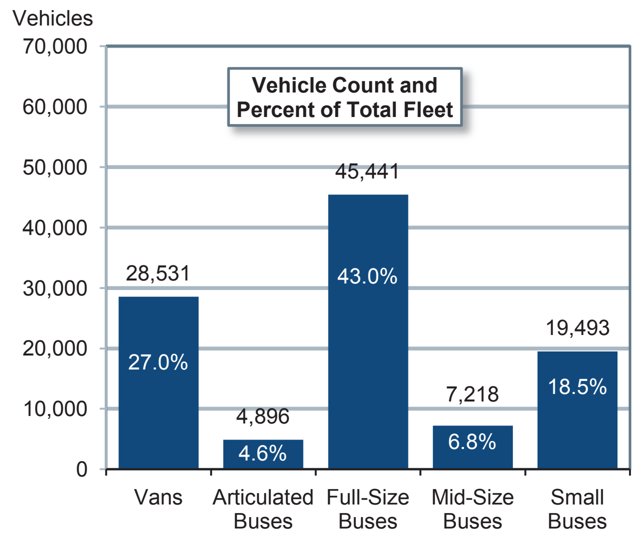
Exhibit 2-21 Transit Active Fleet by Vehicle Type, 2010



Source: National Transit Database.

Exhibit 2-22 shows the composition of the Nation's urban transit road vehicle fleet in 2010. More than one- third of these vehicles, or 43 percent, are full-sized motor buses. Additional information on trends in the number and condition of vehicles over time is included in Chapter 3. Vans here are the familiar 10-seat passenger vans. Articulated buses are the long vehicles articulated for better maneuverability on city streets. Full-sized buses are the standard 40-foot, 40-seat city buses. Mid-sized buses are in the 30-foot, 30-seat range. Small buses, typically built on truck chassis ("cut-aways"), are shorter and seat around 20 people.

Exhibit 2-22 Composition of Urban Transit Road Vehicle Fleet, 2010



Source: Transit Economic Requirements Model and National Transit Database.

Track, Stations, and Maintenance Facilities

Maintenance facility counts are broken down by mode and by size of urbanized area in *Exhibit 2-23*. Additional data on the age and condition of these facilities is included in Chapter 3.

As shown in *Exhibit 2-24*, in 2010, transit providers operated 12,438 miles of track and served 3,175 stations, compared with 11,864 miles of track and 3,078 stations in 2008. Expansion in light rail track mileage (8.1 percent) and stations (7.8 percent) accounted for most of the increase, a trend that continues from the recent past. The Nation's rail system mileage is dominated by the longer distances generally covered by commuter rail. Light and heavy rail typically operate in more densely developed areas and have more stations per track mile.

Transit System Resiliency

Transit systems practice resiliency by operating through all but the worst weather on a daily basis. Most play a key role in community emergency response plans. Dispatchers and vehicle operators receive special training for these circumstances. Bus systems all have reserve fleets that can replace damaged vehicles on short notice. Rail systems have contingency plans for loss of key assets and most can muster local resources to operate bus bridges in emergency situations. Operationally speaking, transit providers are some of the most resilient community institutions. However, much transit infrastructure has not yet been upgraded to address changing climactic patterns. FTA does not collect systematic data on this, but a significant amount of grant money has been made available for transit systems to upgrade their structures and guideways to be more resistant to extreme precipitation events, sea level rise, storm surge, heat waves, and other environmental stress. This is particularly evident in the aftermath of "superstorm" Sandy. Addressing these issues is a common use of FTA grant funds.

Exhibit 2-23 Maintenance Facilities for Directly Operated Services, 2010

Maintenance Facility Type[1]	Population Category: Over 1 Million	Population Category: Under 1 Million	Total
Heavy Rail	59	0	59
Commuter Rail	51	1	52
Light Rail	37	6	43
Other Rail[2]	3	4	7
Motorbus	316	245	561
Demand Response	37	84	122
Ferryboat	8	1	9
Other Nonrail[3]	6	3	8
Total Urban Maintenance Facilities	**516**	**344**	**860**
Rural Transit [4]		**682**	**682**
Total Maintenance Facilities	**516**	**1,026**	**1,542**

[1] Includes owned and leased facilities.

[2] Alaska railroad, automated guideway, cable car, inclined plane, and monorail.

[3] Aerial tramway, jitney, Público, and vanpool.

[4] Vehicles owned by operators receiving funding from FTA as directed by 49 USC Section 5311. These funds are for transit services in areas with populations of less than 50,000. (Section 5311 Status of Rural Public Transportation 2000, Community Transportation Association of America, April 2001.)

Source: National Transit Database.

Exhibit 2-24 Transit Rail Mileage and Stations, 2010

Urbanized Area Track Mileage	
Heavy Rail	2,272
Commuter Rail	7,786
Light Rail	1,664
Other Rail and Tramway*	715
Total Urbanized Area Track Mileage	**12,438**
Urbanized Area Transit Rail Stations Count	
Heavy Rail	1,041
Commuter Rail	1,225
Light Rail	848
Other Rail and Tramway	61
Total Urbanized Area Transit Rail Stations	**3,175**

** Alaska railroad, automated guideway, cable car, inclined plane, monorail, and aerial tramway.*

Source: National Transit Database.

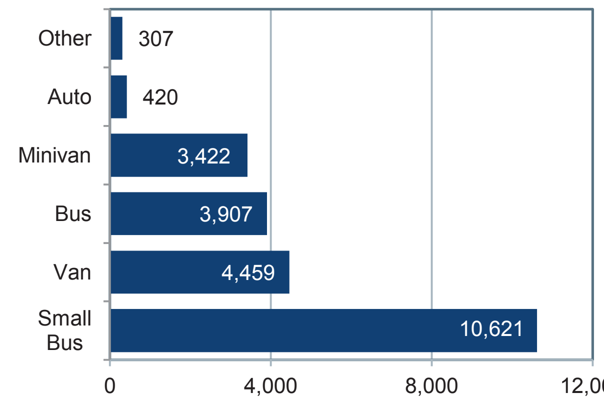
Rural Transit Systems (Section 5311 Providers)

The FTA first instituted rural data reporting to the NTD in 2006. In 2010, 1,582 transit operators reported providing rural service. They reported 123.2 million unlinked passenger trips and 570 million vehicle revenue miles. This included 61 Indian tribes that provided 1,008,701 unlinked passenger trips. There are 327 urbanized areas that report providing rural service; they added another 24 million unlinked passenger trips and 37 million vehicle revenue miles.

The data indicates that rural transit service has been growing rapidly; however, because the NTD is still adding rural reporters, this cannot yet be validated. The data also indicate every State and four territories provide some form of rural transit service.

Rural systems provide both traditional fixed-route and demand response services, with 1,180 demand response services, 530 motor bus services, and 16 vanpool services. They reported 23,136 vehicles in 2010. *Exhibit 2-25* shows the number of rural transit vehicles in service.

Exhibit 2-25 **Rural Transit Vehicles, 2010**



Note: Other includes over-the-road bus, school bus, sport utility vehicle, and other similar vehicles.

Source: National Transit Database.

Transit System Characteristics for Americans with Disabilities and the Elderly

The Americans with Disabilities Act (ADA) is intended to ensure that persons with disabilities have access to the same facilities and services as other Americans, including transit vehicles and facilities. This equality of access is brought about through the upgrading of transit vehicles and facilities on regular routes, through the provision of demand response transit service for those individuals who are still unable to use regular transit service, and through special service vehicles operated by private entities and some public organizations, often with the assistance of FTA funding.

Since the passage of the ADA in 1990, transit operators have been working to upgrade their regular vehicle fleets and improve their demand response services in order to meet the ADA's requirement to provide persons with disabilities with a level of service comparable to that of fixed-route systems. U.S. DOT regulations provide minimum guidelines and accessibility standards for buses; vans; and heavy, light, and commuter rail vehicles. For example, commuter rail transportation systems are required to have at least one accessible car per train and all new cars must be accessible. The ADA deems it discriminatory for a public entity providing a fixed-route transit service to provide disabled individuals with services that are inferior to those provided to nondisabled individuals.

The overall percentage of transit vehicles that are ADA compliant has not significantly changed in recent years. In 2010, 79.3 percent of all transit vehicles reported in the NTD were ADA compliant. This percentage has increased slightly from 79.0 percent in 2008 and, more substantially, from 73.3 percent reported for 2000. The percentage of vehicles compliant with the ADA for each mode is shown in *Exhibit 2-26*.

In addition to the services provided by urban transit operators, a recent survey by the University of Montana found that, in 2002, there were 4,836 private and nonprofit agencies that received funding from FTA for Transportation for Elderly Persons and Persons with Disabilities. This funding supports "special" transit

services (i.e., demand response) to persons with disabilities and the elderly. These providers include religious organizations, senior citizen centers, rehabilitation centers, nursing homes, community action centers, sheltered workshops, and coordinated human services transportation providers.

In 2002, the most recent year for which data are available, these providers were estimated to be using 37,720 special service vehicles. Approximately 62 percent of these special service providers were in rural areas and 38 percent were in urbanized areas. Data collected by FTA show that approximately 76 percent of the vehicles purchased in fiscal year (FY) 2002 were wheelchair accessible, about the same as in the previous few years.

The ADA requires that new transit facilities and alterations to existing facilities be accessible to the disabled. In 2010, 75.9 percent of total transit stations were ADA compliant. This is an increase from the 2008 count, in which 73.7 percent were compliant. Earlier data on this issue may not be comparable to data provided in this report due to improvements in reporting quality *Exhibit 2-27* gives data on the number of urban transit ADA stations by mode.

Under the ADA, FTA was given responsibility for identifying key rail stations and facilitating the accessibility of these stations to disabled persons by July 26, 1993. Key rail stations are identified on the basis of the following criteria:

- The number of passengers boarding at the key station exceeds the average number of passengers boarding on the rail system as a whole by at least 15 percent.
- The station is a major point where passengers shift to other transit modes.
- The station is at the end of a rail line, unless it is close to another accessible station.
- The station serves a "major" center of activities, including employment or government centers, institutions of higher education, and major health facilities.

Although ADA legislation required all key stations to be accessible by July 26, 1993, the U.S. DOT ADA regulation—Title 49 Code of Federal

Exhibit 2-26 Urban Transit Operators' ADA Vehicle Fleets by Mode, 2010

Transit Mode	Active Vehicles	ADA-Compliant Vehicles	Percent of Active Vehicles ADA Compliant
Rail			
Heavy Rail	11,434	11,035	96.5%
Commuter Rail	6,976	3,776	54.1%
Light Rail	2,155	1,803	83.7%
Alaska Railroad	96	30	31.3%
Automated Guideway	51	51	100.0%
Cable Car	39	0	0.0%
Inclined Plane	8	6	75.0%
Monorail	8	8	100.0%
Total Rail	**20,767**	**16,709**	**80.5%**
Nonrail			
Motor Bus	64,552	63,780	98.8%
Demand Response	30,512	24,821	81.3%
Vanpool	11,711	136	1.2%
Ferryboat	131	104	79.4%
Trolleybus	571	571	100.0%
Público	5,620	0	0.0%
Total Nonrail	**113,097**	**89,412**	**79.1%**
Total All Modes	**133,864**	**106,121**	**79.3%**

Source: National Transit Database.

Exhibit 2-27 Urban Transit Operators' ADA-Compliant Stations by Mode, 2010

Transit Mode	Total Stations	ADA-Compliant Stations	Percent of Stations ADA Compliant
Rail			
Heavy Rail	1,041	522	50.1%
Commuter Rail	1,225	798	65.1%
Light Rail	848	734	86.6%
Alaska Railroad	10	10	100.0%
Automated Guideway	41	40	97.6%
Inclined Plane	8	7	87.5%
Monorail	2	2	100.0%
Total Rail	**3,175**	**2,113**	**66.6%**
Nonrail			
Motor Bus	1,462	1,395	95.4%
Ferryboat	82	77	93.9%
Trolleybus	5	5	100.0%
Total Nonrail	**1,549**	**1,477**	**95.4%**
Total All Modes	**4,724**	**3,590**	**76.0%**

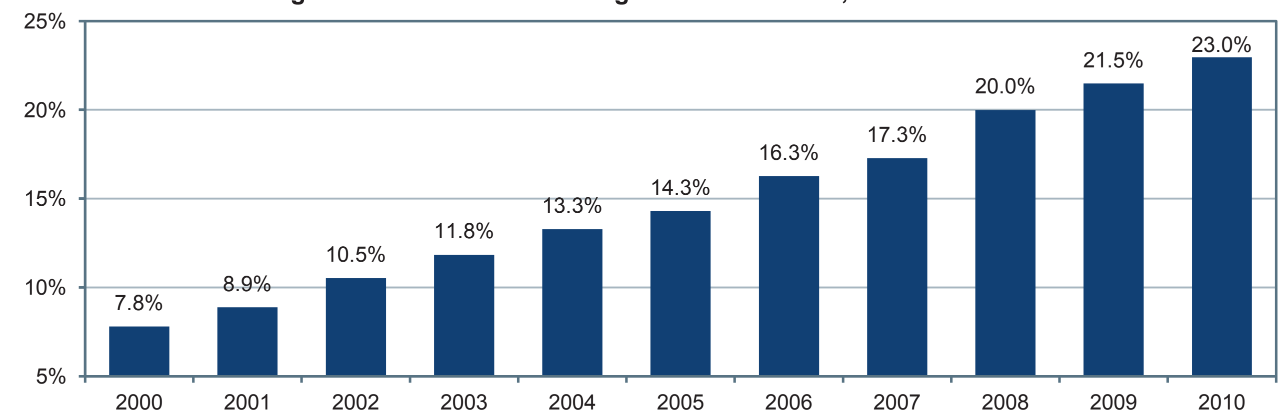
Source: National Transit Database.

Regulations (CFR) Part 37.47(c)(2)—permitted the FTA Administrator to grant extensions up to July 26, 2020, for stations that required extraordinarily expensive structural modifications to achieve compliance. In 2008, there were 687 key rail stations, of which 27 stations (3.9 percent) were under FTA-approved time extensions. The total number of key rail stations has changed slightly over the years as certain stations have closed. As of February 8, 2012, there were 680 key rail stations, 664 stations were accessible and compliant or accessible but not fully compliant (97.6 percent). "Accessible but not fully compliant" means that these stations are functionally accessible (i.e., persons with disabilities, including wheelchair users, can make use of the station), but there are still minor outstanding issues that must be addressed in order to be fully compliant; these usually involve things like missing or mislocated signage and parking-lot striping errors. There are 16 key rail stations that are not yet compliant and are in the planning, design, or construction stage at this time. Of these, eight stations are under FTA-approved time extensions up to 2020 (as provided under 49 CFR §37.47[c][2]), one of which will expire on June 26, 2012. The FTA continues to focus its attention on the eight stations that are not fully accessible and are not under a time extension, as well as on the eight stations with time extensions that will be expiring in the coming years.

Transit System Characteristics: Alternative Fuel Vehicles

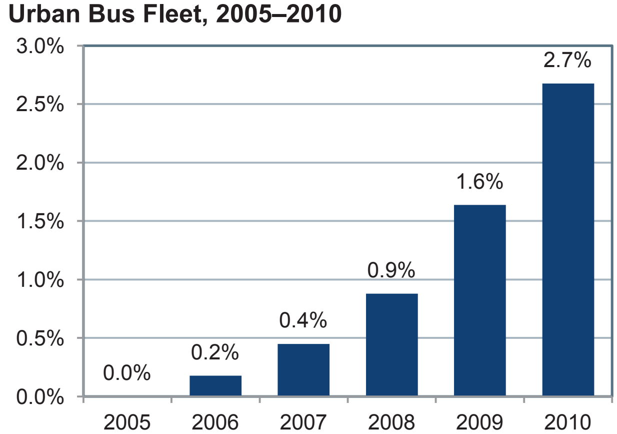
Exhibit 2-28 indicates that the share of alternative fuel buses increased from 7.8 percent in 2000 to 23.0 percent in 2010. In 2010, 12.9 percent of buses used compressed natural gas, 7.9 percent used biodiesel, and 2.0 percent used liquefied natural or petroleum gas. Conventional fuel buses, which make up the majority of the U.S. bus fleet, utilized diesel fuel and gasoline. In 2010, hybrid buses made up 2.7 percent of urban bus fleets as shown in *Exhibit 2-29*. These hybrid vehicles are more efficient than conventional fuel buses, but they are not technically counted as alternative-fuel vehicles.

Exhibit 2-28 **Percentage of Urban Bus Fleet Using Alternative Fuels, 2000–2010**



Source: National Transit Database.

Exhibit 2-29 **Hybrid Buses as a Percentage of Urban Bus Fleet, 2005–2010**



Source: National Transit Database.

CHAPTER 3

System Conditions

Highway System Conditions

Roadway pavement condition can impact the costs of passenger travel and freight transportation. Poor road surfaces cause additional wear and tear on vehicle suspensions, wheels, and tires. Significant congestion and delays can be attributed to vehicles slowing down in heavy traffic to avoid potholes or rough pavement. An increasing frequency of crashes also can be caused by unexpected changes in surface conditions because of reduction of road friction which affects the stopping ability and maneuverability of vehicles.

This section examines the physical conditions of the Nation's roadways, addressing both roadway surface conditions and other condition measures. This information is presented for Federal-aid highways only. Pavement data are not collected in the Highway Performance Monitoring System (HPMS) for roads functionally classified as rural minor collectors, rural local, or urban local. Separate statistics are presented for the National Highway System (NHS). Subsequent sections within this chapter explore the physical conditions of bridges and transit systems. Safety trends and system performance trends are discussed separately in Chapter 4 and Chapter 5.

Pavement Terminology and Measurements

Pavement condition ratings presented in this section are derived from either the International Roughness Index (IRI) or the Present Serviceability Rating (PSR). The IRI objectively measures the cumulative deviation from a smooth surface in inches per mile. The PSR is a subjective rating system based on a scale of 0 to 5. HPMS coding instructions recommend the reporting of IRI data for all facility types. However, States are permitted to instead provide PSR data for roadway sections classified as rural major collectors, urban minor arterials, or urban collectors. The Federal Highway Administration (FHWA) adopted the IRI for the higher functional classifications because it is generally accepted worldwide as a pavement roughness measurement. The IRI system results in more consistent data for trend analyses and cross jurisdiction comparisons.

A conversion table was utilized to translate PSR values into equivalent IRI values to classify mileage for this report. *Exhibit 3-1* contains a description of qualitative pavement condition terms used in this report and corresponding quantitative PSR and IRI values. The translation between PSR and IRI is not exact. IRI values are based on objective measurements of pavement roughness, while PSR is a subjective evaluation of a broader range of pavement characteristics. The term "good ride quality" applies to pavements with an IRI value of less than 95 inches per mile. The term "acceptable ride quality" applies to pavements with an IRI value of less than or equal to 170 inches per mile, which also includes those pavements classified as having good ride quality. It is important to note that the specific IRI values associated with good ride quality and acceptable ride quality were adopted by the FHWA as pavement condition indicators for the NHS. These values are applied to all Federal-aid highways in this report, but States and local governments may have different standards of what constitutes acceptable pavement conditions, particularly for low-volume roadways that are not part of the NHS.

Exhibit 3-1 Pavement Condition Criteria

	All Functional Classifications	
Ride Quality Terms*	IRI Rating	PSR Rating
Good	< 95	≥ 3.5
Acceptable	≤ 170	≥ 2.5

** The rating thresholds for good and acceptable ride quality used in this report were initially determined for use in assessing pavements on the NHS. Some transportation agencies may use less stringent standards for lower functional classification roadways.*

Source: Highway Performance Monitoring System (HPMS).

What are some measures of pavement condition other than IRI?

Other principal measures of pavement condition or distress such as rutting, cracking, and faulting existed but were not included in HPMS until 2010, when the HPMS reporting requirements were modified to collect information on these distresses and other pavement-related data. At the time of this report, data available through the HPMS are incomplete. It is expected that national level summaries will be presented in the 2015 C&P Report.

In addition to allowing more robust assessments of the current state of the Nation's pavements, these new data will support the use of enhanced pavement deterioration equations in the HERS model, which will provide refined projections of future pavement conditions.

Factors Impacting Pavement Performance

Because pavements are continuously exposed to the environment, environmental conditions play a significant part in the ongoing deterioration of pavements. High volumes of traffic and increases in the volume of heavy traffic vehicles also contribute to the deterioration of pavements.

Reconstruction, rehabilitation, or preventive maintenance actions can be taken to mitigate the deterioration caused by these factors. Since the impacts of traffic and the environment are cumulative, deterioration can happen rapidly and, if no action is taken, deterioration of the pavement can continue until the pavement can no longer support traffic loads.

Construction of a new pavement and the major rehabilitation of a pavement are relatively expensive. Consequently, such actions may not be economically justified until the pavement section has deteriorated to a relatively bad condition. Such considerations are reflected in the investment scenarios presented in Part II of this report, which show that even if all cost-beneficial investments were made, at any given time a certain percentage of pavements would not meet the criteria for "acceptable ride quality".

Preventive maintenance actions are less expensive and can be used to maintain and temporarily improve the quality of a pavement section. However, preventive maintenance actions have shorter useful lives than reconstruction or rehabilitation actions; this shorter life results in a more rapid deterioration rate after they are implemented. Preventative maintenance actions are important to preserve the quality of a pavement section but cannot completely address pavement deterioration over the long term. More aggressive actions would eventually need to be taken to preserve pavement quality.

Implications of Pavement Condition for Highway Users

Among the three major components of highway user costs measured in this report (travel time costs, vehicle operating costs, and crash costs), pavement condition has the most direct impact on vehicle operating costs in the form of increased wear and tear on vehicles and repair costs. Poor pavement can also impact travel time costs to the extent that road conditions force drivers to reduce speed. Additionally, poor pavement can increase the frequency of crash rates. Highway user costs are discussed in more detail in Chapter 7.

Good ride quality and acceptable ride quality are defined based on a range of IRI values, and the impact of ride quality on highway user costs varies depending on where pavements fall within these categories. In general, pavements falling below the acceptable ride quality threshold would tend to have greater impacts on user costs than those classified as having acceptable or good ride quality. However, the relative impacts on user costs of a pavement with an IRI of 169 (acceptable) compared with a pavement with an IRI of 171 (not acceptable) would not be significant. The same would be true for pavements just above or below the standard for good ride quality (an IRI of less than or equal to 95).

The impact of pavement ride quality on user costs tends to be higher on the higher functional classification roadways, such as Interstate System highways, than on the roadways with lower functional classifications, such as connectors. Vehicle speed can significantly influence the impact that poor ride quality has on highway user costs. For example, a vehicle encountering a pothole at 55 miles per hour on an Interstate highway would experience relatively more wear and tear than a vehicle encountering an identical pothole on a collector at 25 miles per hour.

Poor ride quality would also tend to have a greater impact on Interstate highways due to their higher traffic volumes. The Interstate System supports the movement of passenger vehicles and trucks at relatively high speeds across the Nation. Poor ride quality can cause drivers to travel at a lower speed, thereby increasing the time of individual trips and adding to congestion. In the case of freight movement, this reduction in travel speed would add to the cost of the delivery of goods. Conversely, because traffic volumes and average speeds on collectors are lower to begin with, poor ride quality on such facilities would not have as great an impact on vehicle speeds as comparable conditions would on higher functional classification roadways.

Q&A

What performance measurement requirements for the National Highway System have been established by MAP-21?

Under MAP-21, States are required to develop a risk- and performance-based asset management plan for the NHS to improve or preserve asset condition and system performance. Plan development process must be reviewed and recertified at least every 4 years. The penalty for failure to implement this requirement is a reduced Federal share for National Highway Performance Program (NHPP) projects in that year (65 percent instead of the usual 80 percent).

Q&A

What are some factors that should be considered in defining a state of good repair for transportation assets?

There is broad consensus that our Nation's transportation infrastructure falls short of a "State of Good Repair"; there is, however, no nationally accepted definition of exactly how the term should be defined in the context of various types of transportation assets.

The condition of some asset types have traditionally been measured by multiple quantitative indicators, which are often weighted differently in the assessment process of different transportation asset owners. Other kinds of assets have traditionally been measured using a single qualitative rating, but this introduces subjectivity into the assessment process because different asset owners or different individual raters might apply such rating criteria differently. Thus, although a "State of Good Repair" goal is conducive to measurement, identifying investments that provide the greatest utility in meeting this goal would require consideration of a broad range of metrics within the context of sound asset management principles. Investment decisions should take into account the life-cycle costs of potential alternatives, including the capital costs, maintenance costs, and user costs associated with alternative strategies.

In establishing performance targets for individual assets, it is important to consider how different metrics would reasonably be expected to vary over the asset's life cycle in response to an analytically sound pattern of capital and maintenance actions. It is important that target thresholds be set at levels high enough to measure overall progress, but not so high that they might inadvertently produce suboptimal decision making.

Another key consideration in setting performance targets is how particular assets are utilized. The physical condition of a heavily used asset will, by definition, impact more users than that of a lightly used asset. Applying higher performance standards to heavily used assets would help to capture their greater impact on the traveling public. Also, in selecting potential measures to target, it is important to recognize that some aspects of asset condition have a more direct impact on system users than others. Ideally, the performance measures selected for a given type of asset would roughly reflect the weighting of agency costs and user costs that would be determined as part of a full life-cycle cost analysis for that type of asset.

Other fundamental questions to be answered are whether a particular asset is still serving the purpose for which it was originally intended and whether the long-term benefits that it provides exceed the cost of keeping it in service. A previous decision to invest in an asset should not automatically mean that the asset should be kept in a "State of Good Repair" in perpetuity, without considering the merits of taking the asset out of service.

 FHWA002225

Pavement Ride Quality on the National Highway System

As shown in *Exhibit 3-2,* the share of vehicle miles traveled (VMT) on NHS pavements with acceptable ride quality has changed very little, from approximately 91 percent in 2000 to approximately 93 percent in 2010. However, the share of VMT on NHS pavements meeting the more rigorous standard of good ride quality has risen sharply over time, from approximately 48 percent in 2000 to approximately 60 percent in 2010. As noted above, the percentage of pavements with good ride quality is a subset of the percentage of pavements with acceptable ride quality.

Exhibit 3-2 Percent of NHS VMT on Pavements With Good and Acceptable Ride Quality, 2000–2010

Calendar Year Fiscal Year *	2000 2001	2002 2003	2004 2005	2006 2007	2008 2009	2010 2011
Good (IRI < 95)	48%	50%	52%	57%	57%	60%
Acceptable (IRI ≤ 170)	91%	91%	91%	93%	92%	93%

**The pavement data in this section reflect conditions as of December 31 of each year, as reported in the HPMS. In this report, these values are presented on a calendar-year basis, consistent with the annual Highway Statistics publication. Some other Department of Transportation documents, such as the FY 2011 Performance and Accountability Report, are based on a Federal fiscal year basis; values as of December 31 in one calendar year fall into the next fiscal year. For example, the 60 percent figure identified as good for calendar year 2010 in this exhibit, is reported as a fiscal year 2011 value in the FY 2011 Performance and Accountability Report.*

Source: Highway Performance Monitoring System as of July 2012.

Q&A

What goal was established by the Department of Transportation for pavement ride quality?

The Department of Transportation's FY 2011 Performance and Accountability Report presented a fiscal year (FY) 2011 target of 58 percent for the share of travel on the NHS on pavements with good ride quality; this corresponds to the calendar year 2010 data of 60 percent presented in this report, indicating that this goal was surpassed.

Q&A

What would be the percent VMT on "good" and "acceptable" pavements based on the NHS as newly defined under MAP-21?

Combining data for NHS routes with other principal arterials not on the NHS prior to MAP-21, the share of VMT on the expanded NHS on good pavements is estimated to be 54.7 percent, while the share of VMT on acceptable pavements is estimated to be 88.8 percent. These values are lower than those reported for the old NHS, because principal arterials not included on the MAP-21 NHS tend to have lower ride quality than other NHS routes on average. The values are considered preliminary and may be revised once the expanded NHS has been coded into the HPMS.

The USDOT FY 2013 Performance Plan sets a target for 2013 of having 57 percent of VMT on the expanded NHS to be on pavements with "good" ride quality; the target for 2012 is 56 percent.

Pavement Ride Quality on Federal-Aid Highways

The HPMS collects ride-quality data only for Federal-aid highways, which include all functional classes except for rural minor collectors, rural local, and urban local. As described in Chapter 2, these three functional classifications account for approximately three-fourths of the total mileage on the Nation's system, but carry less than one-sixth of the total daily VMT on the Nation's roadway system. Because the focus of this report is on VMT-based measures of ride quality rather than mileage-based measures, the omission of these functional classes from the statistics in this section is less significant.

As shown in *Exhibit 3-3*, for those functional classes for which data are collected, the VMT on pavements with good ride quality increased from 42.8 percent in 2000 to 50.6 percent in 2010. Between 2008 and 2010, the increase in VMT on pavements with good ride quality increased 4.2 percent. This improvement could be related to the impact of the American Recovery and Reinvestment Act, but further research and data collection is needed to confirm this relationship. The VMT on pavements meeting the standard of acceptable (which includes the category of good) ride quality decreased slightly from 85.4 percent in 2000 to 82.0 percent in 2010.

Exhibit 3-3 **Percent of VMT on Pavements with Good and Acceptable Ride Quality, by Functional System, 2000–2010**

	2000	2002	2004	2006	2008	2010[1]
Functional System	**Percent Good**					
Rural Interstate	69.6%	72.2%	73.7%	78.6%	79.0%	79.1%
Rural Other Freeway & Expressway[2]						74.3%
Rural Other Principal Arterial[2]						72.9%
Rural Other Principal Arterial[2]	56.8%	60.2%	61.0%	66.8%	68.4%	
Rural Minor Arterial	48.9%	51.0%	51.5%	56.3%	56.2%	60.9%
Rural Major Collector	39.9%	42.4%	40.3%	39.8%	39.0%	41.4%
Subtotal Rural	**55.2%**	**58.0%**	**58.3%**	**62.2%**	**62.5%**	**64.6%**
Urban Interstate	43.6%	45.0%	49.4%	54.0%	55.7%	64.6%
Urban Other Freeway and Expressway	32.4%	33.6%	38.8%	45.3%	44.4%	53.3%
Urban Other Principal Arterial	26.9%	25.7%	26.5%	28.8%	26.9%	39.7%
Urban Minor Arterial	34.4%	34.1%	32.3%	33.6%	32.5%	28.8%
Urban Collector[2]	37.9%	35.5%	35.7%	34.1%	31.5%	
Urban Major Collector[2]						25.7%
Urban Minor Collector[2]						8.6%
Subtotal Urban	**35.0%**	**34.9%**	**36.6%**	**39.5%**	**38.9%**	**44.0%**
Total Good[3]	**42.8%**	**43.8%**	**44.2%**	**47.0%**	**46.4%**	**50.6%**
Functional System	**Percent Acceptable**					
Rural Interstate	97.4%	97.3%	97.8%	98.2%	97.3%	91.1%
Rural Other Freeway & Expressway[2]						93.7%
Rural Other Principal Arterial[2]						93.0%
Rural Other Principal Arterial[2]	96.0%	96.2%	96.1%	97.0%	97.6%	
Rural Minor Arterial	93.1%	93.8%	94.3%	95.1%	94.5%	87.3%
Rural Major Collector	86.9%	87.6%	88.5%	87.8%	88.3%	81.2%
Subtotal Rural	**93.8%**	**94.1%**	**94.5%**	**94.9%**	**94.8%**	**87.8%**
Urban Interstate	91.2%	89.6%	90.3%	92.7%	91.9%	89.8%
Urban Other Freeway and Expressway	87.2%	87.8%	87.7%	92.1%	91.4%	89.2%
Urban Other Principal Arterial	71.0%	71.0%	72.6%	73.8%	72.4%	76.4%
Urban Minor Arterial	76.5%	76.3%	73.8%	75.6%	75.5%	70.6%
Urban Collector[2]	76.1%	74.6%	72.6%	72.6%	72.0%	
Urban Major Collector[2]						67.0%
Urban Minor Collector[2]						26.2%
Subtotal Urban	**80.3%**	**79.8%**	**79.7%**	**81.7%**	**81.0%**	**79.4%**
Total Acceptable[3]	**85.5%**	**85.3%**	**84.9%**	**86.0%**	**85.4%**	**82.0%**

[1] HPMS pavement reporting requirements were modified in 2009 to include bridges; features such as open grated bridge decks or expansion joints can greatly increase the IRI for a given section.

[2] 2010 data reflects revised HPMS functional classifications. Rural Other Freeways and Expressways have been split out of the Rural Other Principal Arterial category, and Urban Collect has been split into Urban Major Collector and Urban Minor Collector.

[3] Totals shown reflect Federal-aid highways only and exclude roads classified as rural minor collector, rural local, or urban local, for which pavement data are not reported in HPMS.

Source: Highway Performance Monitoring System as of July 2012.

As noted in Chapter 2, rural areas contain about three-fourths of national road miles, but support only about one-third of annual national VMT. Consequently, pavement conditions in urban areas have a greater impact on the VMT-weighted measure shown in *Exhibit 3-3* than do pavement conditions in rural areas. Pavement conditions are generally better in rural areas. For those functional systems for which data are available, the share of rural VMT on pavements with good ride quality rose from 55.2 percent in 2000 to 64.6 percent in 2010, while the portion of urban VMT on pavements with good ride quality increased from 35.0 percent in 2000 to 44.0 percent in 2010. The share of VMT on pavements with acceptable ride quality rose slightly between 2000 to 2010 in rural areas and declined slightly in urban areas.

Q&A

What potential impact on pavement performance might be expected due to the American Recovery and Reinvestment Act?

As discussed in Chapter 6, a significant share of Recovery Act funding was directed toward pavement resurfacing. This funding is likely contributing to the increase in the percentage of VMT on pavements with good ride quality shown in *Exhibit 3-3*. However, IRI reporting in HPMS is conducted on a 2-year cycle, so some impacts of Recovery Act investment will not immediately be reflected in the data. Also, to the extent to which IRI was measured on sections while resurfacing projects were underway, the data may reflect much higher pavement roughness temporarily experienced by drivers during construction (when driving on grooved pavement, for example).

Pavement Ride Quality by Functional Classification

Percentage of VMT on pavements rated as having good ride quality increased in both the rural and urban areas during the period from 2000 to 2010. In rural areas the increase was from 55.2 percent to 64.6 percent, while in the urban areas the increase was from 35.0 percent to 44.0 percent. The total increase in VMT on good ride quality pavements was from 42.8 percent in 2000 to 50.6 percent in 2010. The percentage of VMT on pavements with acceptable ride quality fell slightly from 85.4 percent in 2000 to 82.0 percent in 2010. A total of 91.1 percent of all VMT on the rural portion of the Interstate System occurred on pavements with acceptable ride quality; the comparable share on the urban portion of the Interstate System was 89.8 percent.

Among all of the functional systems identified in *Exhibit 3-3*, the rural portion of the Interstate System had the highest percentage of VMT on pavements with good ride quality in 2010, at 79.1 percent, up from 69.6 percent in 2000. The share of urban Interstate System VMT on pavements with good ride quality from 2000 to 2010 rose from 43.6 percent to 64.6 percent, which represents the largest increase among the functional systems for which data are available.

Q&A

What is the significance of the differing results shown for VMT-weighted pavement condition shown in *Exhibit 3-3* versus pavement condition on a mileage basis shown in *Exhibit 3-4?*

While the percentage of pavements with good ride quality based on mileage has declined from 2002 through 2010, the percent of VMT on pavements with good ride quality improved during this period. This result appears consistent with a change in philosophy among many transportation agencies leading them to move away from a simple strategy of addressing assets on a “worst first” basis towards more comprehensive strategies aimed at targeting investment where it will benefit the most users. For example, while the *Federal Highway Administration 1998 National Strategic Plan* included a target for pavement ride quality for NHS mileage, by the time of the *FHWA Fiscal Year 2003 Performance Plan*, the target had been modified to a VMT-weighted measure.

Pavement Ride Quality by Mileage

Exhibit 3-4 shows the pavement ride quality by functional classification from 2000 to 2010 based on mileage rather than VMT. On a mileage basis, the percentage of pavements with both good and acceptable ride quality declined between 2000 and 2010. Consistent with the VMT-weighted figures presented earlier, the share of pavements with good ride quality decreased for all functional classes except urban Interstate. The share of pavements with acceptable ride quality increased for rural principal arterials, rural minor arterials, urban Interstate, urban other freeway & expressway, and urban other principal arterials.

Exhibit 3-4 Percent of Mileage with Acceptable and Good Ride Quality, by Functional System, 2000–2010

	2000	2002	2004	2006	2008	2010[1]
Functional System	**Percent Good**					
Rural Interstate	68.5%	71.9%	72.9%	77.2%	78.2%	73.8%
Rural Other Freeway & Expressway[2]						75.3%
Rural Other Principal Arterial[2]						63.2%
Rural Other Principal Arterial[2]	57.4%	60.9%	60.1%	65.3%	66.5%	
Rural Minor Arterial	47.7%	50.2%	47.6%	53.3%	53.3%	49.7%
Rural Major Collector	36.2%	43.1%	36.3%	35.1%	34.0%	28.7%
Subtotal Rural	**46.5%**	**50.9%**	**47.0%**	**45.4%**	**44.9%**	**40.0%**
Urban Interstate	50.0%	50.9%	55.0%	59.3%	61.4%	63.2%
Urban Other Freeway and Expressway	38.7%	40.9%	44.6%	50.2%	50.6%	48.0%
Urban Other Principal Arterial	26.9%	25.7%	26.2%	29.7%	27.4%	26.7%
Urban Minor Arterial	37.7%	38.8%	35.7%	33.0%	32.1%	22.2%
Urban Collector[2]	31.0%	33.4%	31.2%	30.1%	28.3%	
Urban Major Collector[2]						16.6%
Urban Minor Collector[2]						32.6%
Subtotal Urban	**33.6%**	**34.3%**	**33.6%**	**33.3%**	**32.0%**	**24.3%**
Total Good[3]	**43.2%**	**46.6%**	**43.1%**	**41.5%**	**40.7%**	**35.1%**
Functional System	**Percent Acceptable**					
Rural Interstate	97.8%	97.8%	98.0%	98.0%	98.0%	94.5%
Rural Other Freeway & Expressway[2]						98.0%
Rural Other Principal Arterial[2]						97.8%
Rural Other Principal Arterial[2]	96.0%	96.6%	95.8%	96.7%	97.1%	
Rural Minor Arterial	92.0%	93.8%	93.9%	94.0%	94.1%	95.7%
Rural Major Collector	82.1%	85.9%	85.8%	84.5%	85.1%	77.3%
Subtotal Rural	**89.0%**	**91.0%**	**90.9%**	**89.0%**	**89.4%**	**84.7%**
Urban Interstate	93.4%	92.2%	92.6%	94.5%	94.4%	96.6%
Urban Other Freeway and Expressway	89.0%	89.5%	90.2%	93.2%	93.3%	95.7%
Urban Other Principal Arterial	71.3%	71.1%	72.7%	74.4%	73.1%	83.0%
Urban Minor Arterial	78.7%	77.3%	76.0%	75.0%	74.7%	67.2%
Urban Collector[2]	75.3%	75.9%	73.5%	67.9%	68.0%	
Urban Major Collector[2]						57.5%
Urban Minor Collector[2]						49.3%
Subtotal Urban	**77.3%**	**76.9%**	**76.5%**	**74.0%**	**73.6%**	**69.4%**
Total Acceptable[3]	**86.0%**	**87.4%**	**86.6%**	**84.2%**	**84.2%**	**80.0%**

[1] HPMS pavement reporting requirements were modified in 2009 to include bridges; features such as open grated bridge decks or expansion joints can greatly increase the IRI for a given section.

[2] 2010 data reflects revised HPMS functional classifications. Rural Other Freeways and Expressways have been split out of the Rural Other Principal Arterial category, and Urban Collect has been split into Urban Major Collector and Urban Minor Collector.

[3] Totals shown reflect Federal-aid highways only and exclude roads classified as rural minor collector, rural local, or urban local, for which pavement data are not reported in HPMS.

Source: Highway Performance Monitoring System as of July 2012.

Lane Width

Lane width affects capacity and safety. Narrow lanes have a lower capacity and can affect the frequency of crashes. As with roadway alignment, lane width is more crucial on functional classifications with higher travel volumes.

Currently, higher functional systems such as the Interstate System are expected to have 12-foot lanes. As shown in *Exhibit 3-5,* approximately 99.0 percent of rural Interstate System miles and 98.6 percent of urban Interstate System miles had minimum 12-foot lane widths in 2008.

In 2008, approximately 49.8 percent of urban collectors have lane widths of 12 feet or greater, but approximately 19.3 percent have 11-foot lanes and 22.9 percent have 10-foot lanes; the remaining 8.1 percent have lane widths of 9 feet or less. Among rural major collectors, 40.5 percent have lane widths of 12 feet or greater, but approximately 25.0 percent have 11-foot lanes and 26.3 percent have 10-foot lanes. Roughly 8.1 percent of rural major collector mileage has lane widths of 9 feet or less.

Exhibit 3-5 Lane Width by Functional Class, 2008

	≥ 12 foot	11 foot	10 foot	9 foot	< 9 foot
Rural					
Interstate	99.0%	1.0%	0.0%	0.0%	0.0%
Other Principal Arterial	90.6%	7.3%	1.4%	0.4%	0.2%
Minor Arterial	72.3%	18.3%	8.5%	0.8%	0.2%
Major Collector	40.5%	25.0%	26.3%	6.0%	2.1%
Urban					
Interstate	98.6%	1.0%	0.1%	0.1%	0.2%
Other Freeway and Expressway	94.8%	3.9%	0.4%	0.1%	0.8%
Other Principal Arterial	79.9%	13.0%	5.5%	0.5%	1.0%
Minor Arterial	64.1%	19.2%	13.6%	1.7%	1.5%
Collector	49.8%	19.3%	22.9%	5.7%	2.4%

Note: The most recent lane width data available through HPMS is for 2008; due to changes in the HPMS data structure, more recent data cannot yet be extracted.

Source: Highway Performance Monitoring System as of December 2009.

Roadway Alignment

The term "roadway alignment" refers to the curvature and grade of a roadway; i.e., the extent to which it swings from side to side and points up or down. The term "horizontal alignment" relates to curvature (how sharp the curves are), while the term "vertical alignment" relates to gradient (how steep a slope is). Alignment adequacy affects the level of service and safety of the highway system. Inadequate alignment may result in speed reductions and impaired sight distance. Trucks are particularly affected by inadequate vertical alignment with regard to speed. Alignment adequacy is evaluated on a scale from Code 1 (best) to Code 4 (worst).

Alignment adequacy is more important on roads with higher travel speeds and/or higher volumes (e.g., the Interstate System). Because alignment is generally not a major issue in urban areas, only rural alignment statistics are presented in this section. The amount of change in roadway alignment over time is gradual and occurs only during major reconstruction of existing roadways. New roadways are constructed to meet current vertical and horizontal alignment criteria and, therefore, do not generally have alignment problems except under very extreme conditions.

As shown in *Exhibit 3-6,* in 2008, approximately 95.6 percent of rural Interstate System miles were classified as Code 1 for horizontal alignment and 92.7 percent as Code 1 for vertical alignment. In contrast, the percentage of rural minor arterial miles classified as Code 1 for horizontal and vertical alignment, respectively, were only 72.8 percent and 55.1 percent.

Exhibit 3-6 Rural Alignment by Functional Class, 2008

	Code 1	Code 2	Code 3	Code 4
Horizontal				
Interstate	95.6%	0.4%	1.2%	2.8%
Other Principal Arterial	77.9%	8.5%	5.0%	8.6%
Minor Arterial	72.8%	6.3%	7.5%	13.5%
Major Collector	88.0%	0.9%	0.9%	10.3%
Vertical				
Interstate	92.7%	6.0%	0.8%	0.5%
Other Principal Arterial	67.4%	21.3%	6.2%	5.1%
Minor Arterial	55.1%	23.6%	13.2%	8.1%
Major Collector	63.6%	21.1%	9.9%	5.4%

Code 1 All curves and grades meet appropriate design standards.

Code 2 Some curves or grades are below design standards for new construction, but curves can be negotiated safely at prevailing speed limits. Truck speed is not substantially affected.

Code 3 Infrequent curves or grades occur that impair sight distance or severely affect truck speeds. May have reduced speed limits.

Code 4 Frequent grades occur that impair sight distance or severely affect truck speeds. Generally, curves are unsafe or uncomfortable at prevailing speed limit, or the speed limit is severely restricted due to the design speed limits of the curves.

Note: The most recent alignment data available through HPMS is for 2008; due to changes in the HPMS data structure, more recent data cannot yet be extracted.

Source: Highway Performance Monitoring System as of December 2009.

Bridge System Conditions

The data used to evaluate the condition of the Nation's bridges is drawn from the National Bridge Inventory (NBI) and reflects information gathered by States during their periodic safety inspections of bridges. Bridge inspectors are trained to inspect bridges based on the criteria in the National Bridge Inspection Standards (NBIS), at a minimum. Regular inspections are required for all 604,485 bridges with spans of more than 20 feet (6.1 meters) located on public roads. **All data presented in this section are from the NBI database as of December 2010.** Some of the statistics presented in this section are based on actual bridge counts, and others are weighted by bridge deck area (taking bridge size into account) or by average daily traffic (ADT). ADT represents the number of vehicles crossing a structure on a typical day, but does not reflect the length of the structure crossed. In contrast, the VMT-weighted figures for pavements presented in the previous section take into account both the number of vehicles and the distance they travel.

Q&A

How often are the bridges inspected?

Most bridges in the NBI are inspected once every 24 months. Structures with advanced deterioration or other conditions warranting close monitoring may be inspected more frequently. Certain types of structures in satisfactory or better condition—also considering other factors, including but not limited to structure type and description, structure age, and structure load rating—may receive an exemption from the 24-month inspection cycle. With FHWA approval, these structures may be inspected at intervals that do not exceed 48 months. A discussion of the criteria can be found in Technical Advisory 5140.21, subparagraph 7 of Varying the Frequency of Routine Inspection (http://staffnet/pgc/results.cfm?id=2341).

Approximately 83 percent of bridges are inspected once every 24 months, 12 percent are inspected on a 12-month cycle, and 5 percent are inspected on a maximum 48-month cycle.

Bridge Ratings

From the information collected through the inspection process, assessments are performed to determine the adequacy of a structure to service the current structural and functional demands; factors considered include load-carrying capacity, deck geometry, clearances, waterway adequacy, and approach roadway alignment. Structural assessments together with ratings of the physical condition of key bridge components determine whether a bridge should be classified as "**structurally deficient**." Functional adequacy is assessed by comparing the existing geometric configurations and design load-carrying capacities to current standards and demands. Disparities between the actual and preferred configurations are used to determine whether a bridge should be classified as "**functionally obsolete**."

Q&A

What makes a bridge structurally deficient, and are structurally deficient bridges unsafe?

Structurally deficient bridges are *not* inherently unsafe.

Bridges are considered structurally deficient if significant load-carrying elements are found to be in poor or worse condition due to deterioration and/or damage, or if the adequacy of the waterway opening provided by the bridge is determined to be extremely insufficient to the point of causing intolerable roadway traffic interruptions.

The classification of a bridge as structurally deficient does not imply that it is likely to collapse or that it is unsafe. By conducting properly scheduled inspections, unsafe conditions may be identified; if the bridge is determined to be unsafe, the structure must be closed. A deficient bridge, when left open to traffic, typically requires significant maintenance and repair to remain in service and eventual rehabilitation or replacement to address deficiencies. To remain in service, structurally deficient bridges often have weight limits that restrict the gross weight of vehicles using the bridges to less than the maximum weight typically allowed by statute.

How does a bridge become functionally obsolete?

Functional obsolescence is a function of the geometrics of the bridge in relation to the geometrics required by current design standards. In contrast to structural deficiencies, which are generally the result of deterioration of the conditions of the bridge components, functional obsolescence generally results from changing traffic demands on the structure.

Facilities, including bridges, are designed to conform to the design standards in place at the time they are designed. Over time, improvements are made to the design requirements. As an example, a bridge designed in the 1930s would have shoulder widths in conformance with the design standards of the 1930s, but current design standards are based on different criteria and require wider bridge shoulders to meet current safety standards. The difference between the required, current-day shoulder width and the 1930s' designed shoulder width represents a deficiency. The magnitude of these types of deficiencies determines whether a bridge is classified as functionally obsolete.

Condition Ratings

The primary considerations in classifying structural deficiencies are the bridge component condition ratings. The NBI database contains condition ratings on the three primary components of a bridge: deck, superstructure, and substructure. The bridge deck is the surface on which vehicles travel and is supported by the superstructure. The superstructure transfers the load of the deck and bridge traffic to the substructure, which provides support for the entire bridge.

If a bridge has issues that would warrant classification as both structurally deficient and functionally obsolete, which classification takes precedence?

In such cases, the standard NBI data reporting convention is to identify the bridge as structurally deficient because structural deficiencies are considered more critical. Thus, while a significant percentage of bridges classified as structurally deficient will also have functional issues in need of correction, bridges classified as functionally obsolete do not have significant structural deficiencies.

Condition ratings have been established to measure the state of bridge components over time in a consistent and uniform manner. Bridge inspectors assign condition ratings by evaluating the severity of any deterioration of bridge components relative to their as-built condition, and the extent to which this deterioration affects the performance of the component being rated. These ratings provide an overall characterization of the general condition of the entire component being rated; the condition of specific individual bridge elements may be higher or lower. *Exhibit 3-7* describes the bridge condition ratings in more detail.

The condition ratings for bridges in the Nation are shown in *Exhibit 3-8*. When a primary component of a structure has a rating of 4 or lower, it is considered to be structurally deficient. A structural deficiency does not indicate that a bridge is unsafe but instead indicates the extent to which a bridge has depreciated from its original condition when first built. Once bridge components become structurally deficient, the bridge may experience reduced performance in the form of lane closures or load limits. Bridges are closed to traffic if they have components in such disrepair that there is a safety risk.

How many of bridges reported in the NBI are currently closed?

Of the structures reported in the NBI, 3,585 (0.6 percent) are currently closed to traffic. Closed bridges are generally removed from the inventory 5 years after closure, unless there are special circumstances, such as active work underway that will permit the structure to be reopened in the future.

Exhibit 3-7 Bridge Condition Rating Categories

Rating	Condition Category	Description*
9	Excellent	
8	Very Good	No problems noted.
7	Good	Some minor problems.
6	Satisfactory	Structural elements show some minor deterioration.
5	Fair	All primary structural elements are sound but may have minor section loss, cracking, spalling, or scour.
4	Poor	Advanced section loss, deterioration, spalling, or scour.
3	Serious	Loss of section, deterioration, spalling, or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2	Critical	Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored, it may be necessary to close the bridge until corrective action is taken.
1	Imminent Failure	Major deterioration or section loss present in critical structural components, or obvious loss present in critical structural components, or obvious vertical or horizontal movement affecting structural stability. Bridge is closed to traffic, but corrective action may be sufficient to put the bridge back in light service.
0	Failed	Bridge is out of service and is beyond corrective action.

**The term "section loss" is defined in The Bridge Inspector's Reference Manual (BIRM) Publication No. FHWA NHI 03-001 as the loss of a (bridge) member's cross-sectional area usually by corrosion or decay. A "spall" is a depression in a concrete member resulting from the separation and removal of a volume of the surface concrete. Spalls can be caused by corroding reinforcement, friction from thermal movement, and overstress. The term "scour" refers to the erosion of streambed or bank material around bridge supports due to flowing water.*

Source: Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges, Report No. FHWA-PD-96-001.

Approximately 58.9 percent of the bridges rated had bridge decks with ratings of 7 or better. Weighting bridges by deck area changes this value to 59.4 percent, suggesting that larger bridges are in slightly better shape on average; the corresponding value weighted by ADT is 55.6 percent, suggesting that bridge decks on heavily traveled bridges are in slightly worse shape on average. The share of bridge decks with ratings of 4 or worse was 5.5 percent based on raw bridge counts or weighted by ADT; the corresponding figure weighted by deck area was 5.0 percent.

Weighted by deck area, the share of bridge superstructures with ratings of 7 or better was 65.4 percent, while the comparable value for bridge substructures was 64.8 percent. The share of bridge superstructures weighted by deck area having a rating of 4 or worse was 3.8 percent, compared to 3.5 percent for bridge substructures. The percentages shown in *Exhibit 3-8* do not reflect culverts, which do not have a deck, superstructure, or substructure, but instead are self-contained units typically located under roadway fill.

Exhibit 3-8 Bridge Condition Ratings, 2010

Deck Rating Distribution			
Rating *	By Bridge Count	Weighted by Deck Area	Weighted by ADT
9	4.0%	2.9%	2.0%
8	17.4%	15.2%	11.3%
7	37.5%	41.3%	42.2%
6	23.2%	24.9%	26.5%
5	12.4%	10.7%	12.4%
4	4.0%	3.7%	4.1%
3	1.0%	1.0%	1.2%
2	0.3%	0.1%	0.1%
1	0.1%	0.1%	0.1%
0	0.2%	0.1%	0.0%

Superstructure Rating Distribution			
Rating*	By Bridge Count	Weighted by Deck Area	Weighted by ADT
9	4.6%	3.8%	2.7%
8	22.8%	24.8%	22.4%
7	34.0%	36.8%	41.9%
6	21.4%	21.1%	21.9%
5	11.6%	9.8%	8.6%
4	3.9%	2.9%	2.1%
3	1.1%	0.6%	0.4%
2	0.3%	0.2%	0.1%
1	0.1%	0.0%	0.0%
0	0.2%	0.1%	0.0%

Substructure Rating Distribution			
Rating*	By Bridge Count	Weighted by Deck Area	Weighted by ADT
9	4.3%	3.4%	2.2%
8	17.5%	17.0%	12.6%
7	36.0%	44.4%	51.2%
6	22.7%	22.1%	23.2%
5	12.5%	9.6%	8.5%
4	4.9%	2.8%	1.9%
3	1.3%	0.5%	0.2%
2	0.5%	0.1%	0.0%
1	0.1%	0.0%	0.0%
0	0.2%	0.1%	0.0%

** Percentages are based on deck ratings for 468,466 bridges, superstructure ratings for 473,116 bridges, and substructure ratings for 473,305 bridges. These percentages exclude 124,823 culverts (self-contained units located under roadway fill that do not have a deck, superstructure, or substructure), other structures for which these ratings are nonapplicable, and other structures for which no value was coded.*

Source: National Bridge Inventory, December 2010.

Appraisal Ratings

Appraisal ratings compare existing bridge characteristics to the most current standards used for highway and bridge design. Appraisal ratings are a factor used in the classification of bridges as structurally deficient or functionally obsolete. *Exhibit 3-9* describes appraisal rating codes in more detail.

Exhibit 3-9 Bridge Appraisal Rating

Rating	Description
N	Not applicable.
9	Superior to present desirable criteria.
8	Equal to present desirable criteria.
7	Better than present minimum criteria.
6	Equal to present minimum criteria.
5	Somewhat better than minimum adequacy to tolerate being left in place as-is.
4	Meets minimum tolerable limits to be left in place as-is.
3	Basically intolerable requiring a high priority of corrective action.
2	Basically intolerable requiring a high priority of replacement.
1	This value of rating code is not used.
0	Bridge closed.

Source: Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges, Report No. FHWA-PD-96-001.

Deck Geometry, Underclearance, and Approach Alignment Ratings

The primary considerations in determining functional obsolescence are the deck geometry rating, the underclearance rating, and the rating of the alignment of the roadway approaching the bridge.

A deck geometry rating reflects the width of the bridge, the minimum vertical clearance over the bridge, the ADT, the number of lanes on the structure, whether the structure carries two-way or one-way traffic, and the functional classification of the structure. As noted above, appraisal ratings are used to compare existing characteristics of a bridge to

the current standards used for highway and bridge design; thus, when a more stringent standard is adopted, this leads to downward adjustments to the ratings of existing bridges that do not meet the new standard. For example, a bridge built to the design standards for deck width in the 1960s may not meet the current design standards for deck width, and thus would receive a lower deck geometry rating.

Underclearance appraisals consider both the vertical and horizontal distances measured from a roadway or railway passing beneath a bridge to the nearest bridge component. The functional classification of the route passing under the bridge is also considered, along with its Federal-aid designation and defense categorization (i.e., whether the bridge crosses over a Strategic Highway Network [STRAHNET] route).

Approach alignment ratings differ from the appraisal ratings previously discussed in that, rather than comparing approach roadway alignment with a specific set of standards, they are determined by comparing the existing approach roadway alignment to the general alignment for the section of highway on which the bridge is located. Disparities in alignment between a bridge and its approach roadway can pose a hazard to drivers.

Exhibit 3-10 shows the distribution of appraisal ratings for deck geometry, underclearance, and approach alignment. Approximately 34.3 percent of bridges received a deck geometry performance rating of 4 or less, indicating problems that generally would not be correctable unless the structure were

Exhibit 3-10 **Bridge Appraisal Ratings Based on Geometry and Function, 2010**

Deck Geometry Rating Distribution

Rating*	By Bridge Count	Weighted by Deck Area	Weighted by ADT
9	8.9%	21.2%	31.0%
8	2.2%	2.4%	2.0%
7	11.3%	14.4%	12.4%
6	20.7%	16.4%	13.5%
5	22.6%	15.8%	11.7%
4	18.4%	16.5%	14.7%
3	7.2%	4.8%	4.0%
2	8.5%	8.5%	10.8%
1	0.0%	0.0%	0.0%
0	0.1%	0.1%	0.0%

Approach Alignment Rating Distribution

Rating*	By Bridge Count	Weighted by Deck Area	Weighted by ADT
9	2.7%	3.5%	5.4%
8	62.4%	73.2%	79.2%
7	12.3%	10.0%	7.9%
6	14.4%	8.9%	5.5%
5	3.8%	2.1%	1.1%
4	2.8%	1.5%	0.8%
3	1.4%	0.6%	0.2%
2	0.2%	0.1%	0.0%
1	0.0%	0.0%	0.0%
0	0.1%	0.0%	0.0%

Underclearance Rating Distribution

Rating*	By Bridge Count	Weighted by Deck Area	Weighted by ADT
9	10.4%	12.3%	9.1%
8	2.0%	2.0%	1.6%
7	9.1%	8.3%	7.8%
6	17.3%	16.7%	17.1%
5	16.2%	14.2%	15.0%
4	20.3%	19.3%	23.5%
3	21.6%	24.2%	23.4%
2	3.0%	2.9%	2.4%
1	0.0%	0.0%	0.0%
0	0.1%	0.1%	0.0%

** Percentages are based on deck geometry ratings for 519,386 structures, approach alignment ratings for 602,100 structures, and underclearance ratings for 101,860 structures. Underclearance adequacy is rated only for those bridges crossing over a highway or railroad.*

Source: National Bridge Inventory, December 2010.

Additional Factors Affecting Bridge Performance

Load-carrying capacity does not influence the assignment of the condition ratings, but it does factor into the structural evaluation appraisal rating. This is calculated according to the capacity ratings for various categories of traffic in terms of ADT. Depending on how low its rating, a bridge can be classified as functionally obsolete. A very low structural evaluation rating indicates that the load-carrying capacity is too low and the structure should be replaced; in this case, the bridge is classified as structurally deficient. Neither rating is indicative of a bridge that is unsafe, but rather is a measure of the bridge's original design and the extent of the bridge's depreciation relative to current design standards.

The waterway adequacy appraisal rating describes the size of the opening of the structure with respect to the passage of water flow under the bridge. This rating, which considers the potential for a structure to be submerged during a flood event and the potential inconvenience to the traveling public, is based on criteria assigned by functional classification. A sufficiently low waterway adequacy rating for a bridge can result in the bridge being classified as structurally deficient.

replaced. The comparable figure weighted by ADT is 29.5 percent because deck geometry adequacy is more of a problem on higher-traveled routes, on average. Approximately 1.0 percent of approach alignments were rated as having ratings of 4 or worse when weighted by ADT; for those bridges for which underclearance adequacy was evaluated, 49.4 percent had ratings of 4 or lower.

Bridge Conditions

Exhibit 3-11 identifies the percentage of all bridges classified as structurally deficient or functionally obsolete based on the number of bridges, bridges weighted by deck area, and bridges weighted by ADT. The total number of bridges has grown over time; totals for individual years are identified in Chapter 2.

Exhibit 3-11 **Systemwide Bridge Deficiencies, 2000–2010**

	Percentage of Deficient Bridges by Year					
Analysis Approach	2000	2002	2004	2006	2008	2010
By Bridge Count						
Structurally Deficient	15.2%	14.2%	13.5%	12.6%	12.1%	11.7%
Functionally Obsolete	15.5%	15.4%	15.2%	15.0%	14.8%	14.2%
Total Deficient	**30.7%**	**29.6%**	**28.7%**	**27.6%**	**26.9%**	**25.9%**
Weighted by Deck Area						
Structurally Deficient	10.8%	10.4%	10.1%	9.6%	9.3%	9.1%
Functionally Obsolete	20.8%	20.4%	20.5%	20.3%	20.5%	19.8%
Total Deficient	**31.6%**	**30.8%**	**30.6%**	**29.9%**	**29.8%**	**28.9%**
Weighted by ADT						
Structurally Deficient	8.5%	8.0%	7.6%	7.4%	7.2%	6.7%
Functionally Obsolete	23.0%	22.0%	21.9%	21.9%	22.2%	21.5%
Total Deficient	**31.5%**	**30.0%**	**29.5%**	**29.3%**	**29.4%**	**28.2%**

Source: National Bridge Inventory, December 2010.

Based on raw bridge counts, approximately 11.7 percent of bridges were classified as structurally deficient in 2010, and 14.2 percent were classified as functionally obsolete. Weighted by deck area, the comparable shares were 9.1 percent structurally deficient and 19.8 percent functionally obsolete. The differences are even more pronounced when bridges are weighted by ADT, as this adjustment results in a structurally deficient share of 6.7 percent and a functionally obsolete share of 21.5 percent.

Since 2000, the total share of deficient bridges weighted by deck area has decreased from 31.6 percent to 28.9 percent, representing an overall improvement in the condition of the Nation's bridges. Whether considering raw bridge counts, deck-area-weighted values, or ADT-weighted values, more progress was made during this period in reducing the percentage of structurally deficient bridges than in reducing the share of functionally obsolete bridges.

Bridge Conditions on the NHS

Exhibit 3-12 identifies the percent of bridges on the NHS classified as structurally deficient or functionally obsolete based on the number of bridges, bridges weighted by deck area, and bridges weighted by ADT. The total number of NHS bridges for individual years are identified in Chapter 2.

What goal was established by the Department of Transportation for NHS bridges? Q&A

The Department of Transportation's FY 2010 Performance Report presented a FY 2010 target of a maximum 28.9 percent for the share of deck area on NHS bridges that were rated as deficient. The target was met and exceeded. The final percentage was 25.2 percent.

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Exhibit 3-12 NHS Bridge Deficiencies, 2000–2010

	Percentage of Deficient Bridges by Year					
Analysis Approach	2000	2002	2004	2006	2008	2010
Weighted by Deck Area						
Structurally Deficient	8.7%	8.6%	8.9%	8.4%	8.2%	8.3%
Functionally Obsolete	22.0%	21.1%	20.9%	20.8%	21.4%	20.3%
Total Deficient	**30.7%**	**29.7%**	**29.8%**	**29.2%**	**29.6%**	**28.7%**
Weighted by ADT						
Structurally Deficient	7.5%	7.1%	6.8%	6.6%	6.4%	6.0%
Functionally Obsolete	21.4%	20.0%	19.8%	20.1%	20.5%	19.7%
Total Deficient	**28.9%**	**27.1%**	**26.6%**	**26.7%**	**26.9%**	**25.7%**
By Bridge Count						
Structurally Deficient	6.0%	5.9%	5.7%	5.5%	5.4%	5.1%
Functionally Obsolete	17.7%	17.2%	16.9%	16.8%	16.9%	16.3%
Total Deficient	**23.7%**	**23.1%**	**22.6%**	**22.3%**	**22.3%**	**21.4%**

Source: National Bridge Inventory, December 2010.

In 2010, approximately 5.1 percent of NHS bridges were classified as structurally deficient and 16.3 percent were classified as functionally obsolete, resulting in a total of 21.4 percent of the 116,669 NHS bridges classified as deficient; the comparable values weighted by deck area and ADT were 28.7 percent and 25.7 percent, respectively. This suggests that there is a greater-than-average concentration of deficiencies on heavily traveled and larger bridges, respectively.

The FHWA has adopted deck-area weighting for use in agency performance planning in recognition of the significant logistical and financial challenges that may be involved in addressing deficiencies on larger bridges. The share of NHS bridges weighted by deck area that are classified as structurally deficient remained essentially the same from 2000 (8.7 percent) to 2010 (8.3 percent), while the deck-area weighted share classified as functionally obsolete decreased from 22.0 percent to 20.3 percent during the same period. NHS routes tend to carry significantly more traffic than average roads, and functional obsolescence remains a significant challenge on NHS bridges.

Q&A

What provisions are in MAP-21 to support and improve the performance level of bridges on the NHS and on the Interstate System?

The provisions of MAP-21 include the National Highway Performance Program (NHPP) and Surface Transportation Program (STP), each of which provides support for the condition and performance of the Nation's highway bridges. The NHPP specifically provides support for highway bridges on the NHS and the STP provides flexibility for States and localities to preserve and improve the conditions and performance of highway bridges on any public road. The NHPP also establishes a minimum standard for the condition of bridges located on the NHS and a penalty if the standard is not achieved:

> If more than 10% of the total deck area of NHS bridges in a State is on structurally deficient bridges for three consecutive years, the State must devote NHPP funds in an amount equal to 50% of the State's FY 2009 Highway Bridge Program apportionment to improve NHS bridge conditions during the following fiscal year (and each year thereafter if the condition remains below the minimum standard).

Additionally, the provisions for the National Bridge and Tunnel Inventory and Inspection Standards recognize the importance of the safety of the traveling public as well as support the efforts to improve the condition of the Nation's bridges. The purposes of this provision include providing a basis for a data-driven and risk-based approach and a cost-effective strategy to bridge investment, and establishing and maintaining existing minimum Federal standards related to the inventory and safety inspection of bridges on all public roads.

Bridge Conditions on the STRAHNET

The STRAHNET system is a key subset of the NHS. The physical composition of this system was described in Chapter 2 and the condition of the pavement portion was presented earlier in this chapter. The share of structurally deficient bridges decreased from 6.2 percent in 2000 to 4.9 percent in 2010. The share of functionally obsolete bridges decreased from 17.2 percent in 2000 to 16.9 percent in 2010. The share of bridges either structurally deficient or functionally obsolete decreased from 23.4 percent in 2000 to 21.8 percent in 2010. These data are shown in *Exhibit 3-13.*

Exhibit 3-13 STRAHNET-Deficient Bridges

Year	Bridges	Structurally Deficient		Functionally Obsolete		Total Deficient	
	Number	Number	Percentage	Number	Percentage	Number	Percentage
2000	102,856	6,357	6.2%	17,742	17.2%	24,099	23.4%
2002	79,852	4,320	5.4%	13,724	17.2%	18,044	22.6%
2004	72,046	3,640	5.1%	12,444	17.3%	16,084	22.4%
2006	73,003	3,645	5.0%	12,664	17.3%	16,309	22.3%
2008	73,771	3,659	5.0%	12,942	17.5%	16,601	22.5%
2010	68,529	3,355	4.9%	11,613	16.9%	14,968	21.8%

Source: National Bridge Inventory, December 2010.

Bridge Conditions by Functional Classification

Based on the number of bridges, the total percentage of structurally deficient and functionally obsolete bridges on the Nation's roadways decreased from 30.8 percent in 2000 to 25.9 percent in 2010. The percentage of structurally deficient bridges for most functional classes decreased between 2000 and 2010, with the exception of rural Interstate System bridges. As shown in *Exhibit 3-14*, the share of rural Interstate System bridges classified as structurally deficient increased from 4.0 percent to 4.5 percent during this period. The share of bridges classified as functionally obsolete decreased from 15.5 percent in 2000 to 14.2 percent in 2010.

Among the individual functional classes, the highest percentage observed in 2010 for structurally deficient bridges was 17.9 percent for rural local; the rural portion of the Interstate System and rural other principal arterial roadways tied for the lowest percentage of structurally deficient bridges at 4.5 percent. Urban minor arterials had the highest share of functionally obsolete bridges in 2000, at approximately 28.6 percent. The functional class with the lowest share of functionally obsolete bridges in 2010 was rural other principal arterials with 8.5 percent; rural other principal arterials have continuously had the lowest share of functionally obsolete bridges since 2000.

Bridge Conditions by Owner

As discussed in Chapter 2, the entity responsible for the maintenance and operation of a bridge is characterized as its owner. A secondary agency (such as the State) may perform maintenance and operation work under an interagency agreement with the owner (such as a local community). However, such agreements do not transfer ownership and, therefore, do not negate the responsibilities of the bridge owners to ensure that the maintenance and operation of all bridges that they own are in compliance with Federal and State requirements. Each State has the responsibility for inspection of all bridges in that State except for tribally or Federally owned bridges.

Exhibit 3-14 Bridge Deficiencies by Functional Class, 2000–2010

Functional System	Percentage of Structurally Deficient Bridges by Year					
	2000	2002	2004	2006	2008	2010
Rural						
Interstate	4.0%	4.1%	4.3%	4.3%	4.5%	4.5%
Other Principal Arterial	5.6%	5.5%	5.4%	5.1%	4.9%	4.5%
Minor Arterial	9.1%	8.7%	8.4%	8.3%	8.1%	7.3%
Major Collector	12.6%	12.3%	11.7%	11.2%	10.5%	10.2%
Minor Collector	15.2%	14.0%	13.5%	12.7%	12.4%	12.1%
Local	23.9%	22.0%	20.7%	19.1%	18.3%	17.9%
Subtotal Rural	**16.7%**	**15.6%**	**14.8%**	**13.9%**	**13.3%**	**12.9%**
Urban						
Interstate	6.7%	6.5%	6.3%	6.0%	5.9%	5.4%
Other Freeway and Expressway	6.5%	6.4%	6.1%	5.8%	5.5%	5.0%
Other Principal Arterial	10.4%	9.6%	9.2%	8.7%	8.6%	8.2%
Minor Arterial	11.4%	10.9%	10.3%	10.0%	9.8%	9.1%
Collector	12.9%	11.6%	11.1%	11.0%	10.8%	9.9%
Local	13.4%	12.1%	11.5%	11.1%	10.8%	10.3%
Subtotal Urban	**10.2%**	**9.5%**	**9.1%**	**8.8%**	**8.6%**	**8.1%**
Total	**15.2%**	**14.2%**	**13.5%**	**12.6%**	**12.1%**	**11.7%**
Functional System	**Percentage of Functionally Obsolete Bridges by Year**					
	2000	**2002**	**2004**	**2006**	**2008**	**2010**
Rural						
Interstate	13.2%	12.9%	12.8%	12.0%	11.8%	11.6%
Other Principal Arterial	11.1%	10.3%	9.9%	9.4%	9.3%	8.5%
Minor Arterial	12.3%	12.0%	11.6%	11.0%	10.6%	10.2%
Major Collector	11.3%	11.3%	11.0%	10.5%	10.1%	9.3%
Minor Collector	12.8%	12.3%	12.1%	11.9%	11.4%	10.6%
Local	13.6%	13.5%	13.2%	12.8%	12.4%	11.7%
Subtotal Rural	**12.7%**	**12.5%**	**12.2%**	**11.7%**	**11.4%**	**10.7%**
Urban						
Interstate	23.8%	23.0%	23.3%	23.6%	23.9%	23.0%
Other Freeway and Expressway	24.5%	23.5%	23.2%	23.1%	22.9%	22.0%
Other Principal Arterial	25.5%	25.4%	25.4%	24.5%	24.5%	23.8%
Minor Arterial	29.6%	29.3%	29.3%	29.4%	29.3%	28.6%
Collector	28.1%	28.1%	28.6%	28.7%	28.5%	28.1%
Local	21.3%	21.4%	22.0%	21.9%	21.4%	20.5%
Subtotal Urban	**25.2%**	**24.9%**	**25.1%**	**25.0%**	**24.9%**	**24.2%**
Total	**15.5%**	**15.4%**	**15.2%**	**15.0%**	**14.8%**	**14.2%**
Grand Total Deficient	**30.8%**	**29.6%**	**28.6%**	**27.6%**	**26.9%**	**25.9%**

Source: National Bridge Inventory, December, 2010.

Bridge deficiencies by ownership are examined in *Exhibit 3-15*. Of the relatively small number of privately owned bridges reported in the NBI—0.3 percent of the total number of bridges—64.6 percent were classified as deficient in 2010. State-owned bridges had the lowest share of structurally deficient bridges in 2010, at approximately 7.9 percent. Bridges owned by local governments had the lowest share of functionally obsolete bridges, at 12.1 percent. These findings are consistent with the types of bridges owned by the different levels of government; local governments tend to own smaller bridges with lower traffic levels than average, for which functional obsolescence is less of an issue.

Exhibit 3-15 Bridge Deficiencies by Owner, 2010

	Federal	State	Local	Private/ Other*	Total
Count					
Total Bridges	8,145	291,145	303,531	1,667	604,488
Total Deficient	2,016	70,209	82,984	1,077	156,286
Structurally Deficient	672	23,049	46,178	532	70,431
Functionally Obsolete	1,344	47,160	36,806	545	85,855
Percentages					
Percent of Total Inventory Owned	1.3%	48.2%	50.2%	0.3%	100.0%
Percent Deficient	24.8%	24.1%	27.3%	64.6%	25.9%
Percent Structurally Deficient	8.3%	7.9%	15.2%	31.9%	11.7%
Percent Functionally Obsolete	16.5%	16.2%	12.1%	32.7%	14.2%

** Note that these data only reflect bridges for which inspection reports were submitted to the NBI. An unknown number of privately owned bridges are omitted.*

Source: National Bridge Inventory, December 2010.

Bridges by Age

Exhibit 3-16 identifies the age composition of Interstate System bridges, NHS bridges, and all total highway bridges in the Nation. As of 2010, approximately 37.7 percent of the Nation's bridges were between 26 and 50 years old; this share was higher for NHS bridges, at 52.7 percent, while 68.4 percent of the Interstate bridges fell into this age range.

Exhibit 3-16 Bridges by Age Range, as of 2010

	All Bridges		NHS Bridges		Interstate Bridges	
Age Range	Count	Percent	Count	Percent	Count	Percent
0–10 Years	66,877	11.1%	11,824	10.1%	3,637	6.6%
11–25 Years	123,231	20.4%	18,957	16.2%	5,831	10.5%
26–50 Years	228,103	37.7%	61,515	52.7%	37,830	68.4%
51–75 Years	125,274	20.7%	19,610	16.8%	7,810	14.1%
76–100 Years	50,525	8.4%	4,506	3.9%	186	0.3%
>100 Years	10,181	1.7%	212	0.2%	6	0.0%
Not reported	294	0.0%	45	0.0%	35	0.1%
Total	**604,485**	**100.0%**	**116,669**	**100.0%**	**55,335**	**100.0%**

Source: National Bridge Inventory, December 2010.

Approximately 68.5 percent of all bridges are 26 years old or older. The percentage of NHS and Interstate bridges in this group are 73.6 percent and 82.8 percent, respectively. The largest number of bridges for each system is in the 26- to 50-years-of-age group: 37.7 percent of all bridges, 52.7 percent of NHS bridges, and 68.4 percent of Interstate bridges. The large number of bridges with ages of 26 years to 50 years has potential implications in terms of long-term bridge rehabilitation and replacement strategies because the need for such actions may be concentrated within certain time periods rather than being spread out evenly, which might be the case if the original construction of bridges had been spread out more evenly over time. However, a number of other variables such as maintenance practices and environmental conditions also affect when future capital investments might be needed.

What is the average age of the Nation's bridges and has it changed since 2000?

Q&A

The average year of construction in 2000 was 1963 which meant the average age was 37 years. In 2010, the average year of construction was 1971 which results in an average age of 39 years. Therefore, the overall age of the Nation's bridges increased 2 years over a period of 10 years.

In 2000, there were 588,844 bridges listed in the National Bridge Inventory (NBI). Approximately 67.2 percent of these bridges were more than 25 years old and 26.2 percent were over 50 years in age.

By 2010, the number of bridges in the NBI increased to 604,485 bridges. Of these, 68.5 percent were older than 25 years and 30.8 percent were over 50 years old.

Exhibit 3-17 identifies the distribution of bridge deficiencies within the age ranges presented in *Exhibit 3-16*. The percent of bridges classified as either structurally deficient or functionally obsolete generally tends to rise as bridges age. Among Interstate System bridges, 22.0 percent of the bridges constructed between 26 and 50 years ago were classified as deficient; this share rose to 34.5 percent for Interstate System bridges constructed between 51 and 75 years ago. Note that some existing bridges were absorbed into the Interstate System at the time it was designated; some of these structures remain in service today.

Exhibit 3-17 Bridge Deficiencies by Period Built, as of 2010

Age Range of All Bridges	Bridge Count	Structurally Deficient		Functionally Obsolete		All Deficient	
		Count	Percent	Count	Percent	Count	Percent
0–10 Years	66,877	450	0.7%	6,096	9.1%	6,546	9.8%
11–25 Years	123,231	3,055	2.5%	11,059	9.0%	14,114	11.5%
26–50 Years	228,103	21,508	9.4%	30,671	13.4%	52,179	22.9%
51–75 Years	125,274	25,883	20.7%	24,289	19.4%	50,172	40.0%
76–100 Years	50,525	15,430	30.5%	11,078	21.9%	26,508	52.5%
>100 Years	10,181	4,079	40.1%	2,574	25.3%	6,653	65.3%
Null	294	26	8.8%	90	30.6%	116	39.5%
Total	**604,485**	**70,431**	**11.7%**	**85,857**	**14.2%**	**156,288**	**25.9%**
Age Range of NHS Bridges	**Bridge Count**	**Structurally Deficient**		**Functionally Obsolete**		**All Deficient**	
		Count	**Percent**	**Count**	**Percent**	**Count**	**Percent**
0–10 Years	11,824	57	0.5%	1,366	11.6%	1,423	12.0%
11–25 Years	18,957	148	0.8%	1,853	9.8%	2,001	10.6%
26–50 Years	61,515	3,221	5.2%	10,019	16.3%	13,240	21.5%
51–75 Years	19,610	1,839	9.4%	4,824	24.6%	6,663	34.0%
76–100 Years	4,506	581	12.9%	910	20.2%	1,491	33.1%
>100 Years	212	54	25.5%	63	29.7%	117	55.2%
Null	45	2	4.4%	26	57.8%	28	62.2%
Total	**116,669**	**5,902**	**5.1%**	**19,061**	**16.3%**	**24,963**	**21.4%**
Age Range of Interstate Bridges	**Bridge Count**	**Structurally Deficient**		**Functionally Obsolete**		**All Deficient**	
		Count	**Percent**	**Count**	**Percent**	**Count**	**Percent**
0–10 Years	3,637	35	1.0%	654	18.0%	689	18.9%
11–25 Years	5,831	61	1.0%	805	13.8%	866	14.9%
26–50 Years	37,830	2,019	5.3%	6,312	16.7%	8,331	22.0%
51–75 Years	7,810	640	8.2%	2,052	26.3%	2,692	34.5%
76–100 Years	186	19	10.2%	21	11.3%	40	21.5%
>100 Years	6	1	16.7%	1	16.7%	2	33.3%
Null	35	0	0.0%	22	62.9%	22	62.9%
Total	**55,335**	**2,775**	**5.0%**	**9,867**	**17.8%**	**12,642**	**22.8%**

Source: National Bridge Inventory, December 2010.

Historic Bridges on the Nation's Roadways

Of the 604,485 bridges in the NBI, approximately 0.29 percent are registered as historic and an additional 0.64 percent are eligible to be registered. Some historic bridges carry significant traffic volumes; over 17 percent of the bridges on the historic register are on principal arterials.

Bridges do not have to be extremely old to be classified as historic. Approximately 9.5 percent of the registered historic bridges are 50 years old or younger, well within the typical useful lifespan of a bridge; approximately 4.1 percent are 10 years old or less.

Of the registered historic bridges, 33.3 percent are classified as structurally deficient and 40.2 percent are classified as functionally obsolete. At some time, it will be necessary to take mitigation actions on those bridges classified as structurally deficient; however, mitigation actions on the bridges classified as functionally obsolete may not be possible due to their historic classification. These bridges are still open to vehicular traffic even though, in some cases, heavy trucks and similar vehicles may not be allowed to use a particular historic bridge.

The age of a bridge structure is one indicator of its serviceability. However, a combination of several factors impacts the serviceability of a structure, including the original type of design; the frequency, timeliness, effectiveness, and appropriateness of the maintenance activities implemented over the life of the structure; the loading the structure has been subject to during its life; the climate of the area where the structure is located; and any additional stresses from events such as flooding to which the structure has been subjected. As an example, two structures built at the same time, using the same design standards, and in the same climate area can have very different serviceability levels. The first structure may have had increasing loads due to increased heavy truck traffic, lack of maintenance of the deck or the substructure, or lack of rehabilitation work. The second structure may have had the same increases in heavy truck traffic but received correctly timed preventive maintenance activities on all parts of the structure and proper rehabilitation activities. In this case, the first structure would have a very low serviceability level while the second structure would have a high serviceability level.

Transit System Conditions

The condition and performance of the U.S. transit infrastructure should ideally be evaluated by how well it supports the objectives of the transit agencies that operate it. Presumably these objectives include providing fast, safe, cost-effective, and comfortable service that takes people where they want to go. However, the degree to which transit service meets these objectives is difficult to quantify and involves trade-offs that are outside the scope of Federal responsibility. This section reports on the quantity, age, and physical condition of transit assets because these factors determine how well the infrastructure can support any agency's objectives and set a foundation for uniform, consistent measurement. The assets in question include vehicles, stations, guideway, rail yards, administrative facilities, maintenance facilities, maintenance equipment, power systems, signaling systems, communication systems, and structures that carry both elevated and subterranean guideway. Chapter 5 addresses issues relating to the operational performance of transit systems.

The FTA uses a numerical condition rating scale ranging from 1 to 5, detailed in *Exhibit 3-18*, to describe the relative condition of transit assets. A rating of 4.8 to 5.0, or "excellent," indicates that the asset is in nearly new condition or lacks visible defects. At the other end of the scale, a rating of 1.0 to 1.9, or "poor," indicates that the asset needs immediate repair and is not capable of supporting satisfactory transit service.

Exhibit 3-18 Definitions of Transit Asset Conditions

Rating	Condition	Description
Excellent	4.8–5.0	No visible defects, near-new condition.
Good	4.0–4.7	Some slightly defective or deteriorated components.
Adequate	3.0–3.9	Moderately defective or deteriorated components.
Marginal	2.0–2.9	Defective or deteriorated components in need of replacement.
Poor	1.0–1.9	Seriously damaged components in need of immediate repair.

Source: Transit Economic Requirements Model.

The FTA uses the Transit Economic Requirements Model (TERM) to estimate the conditions of transit assets for this report. This model consists of a database of transit assets and deterioration schedules that express asset conditions principally as a function of an asset's age. Vehicle condition is based on an estimate of vehicle maintenance history and major rehabilitation expenditures in addition to vehicle age; the conditions of wayside control systems and track are based on an estimate of use (revenue miles per mile of track) in addition to age. For the purposes of this report, the state of good repair was defined using TERM's numerical condition rating scale. Specifically, this report considers an asset to be in a state of good repair when the physical condition of that asset is at or above a condition rating value of 2.5 (the mid-point of the marginal range). An entire transit system would be in a state of good repair if all of its assets have an estimated condition value of 2.5 or higher. The State of Good Repair benchmark presented in Chapter 8 represents the level of investment required to attain and maintain this definition of a state of good repair by rehabilitating or replacing all assets with estimated condition ratings that are less than this minimum condition value. FTA is currently developing a broader definition of a state of good repair to use as a basis for administering MAP-21 grant programs and requirements that are intended to foster better infrastructure re-investment practices across the industry. This definition may not be the same as the one used in this report.

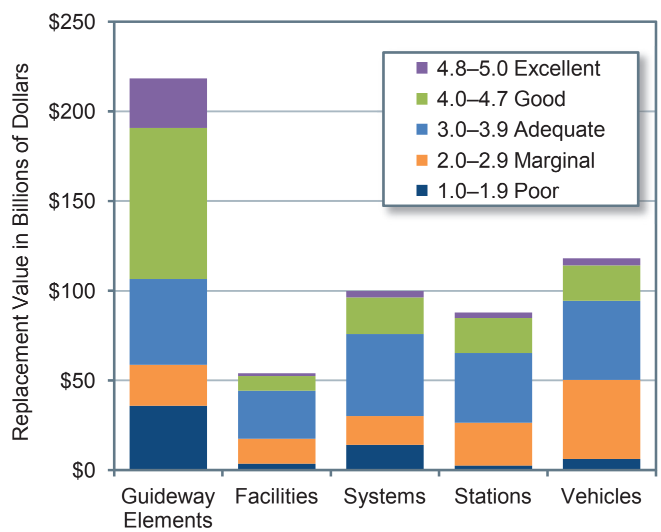
Typical deterioration schedules for vehicles, maintenance facilities, stations, train control systems, electric power systems, and communication systems have been estimated by FTA through special on-site engineering surveys. Transit vehicle conditions also reflect the most recent information on vehicle age, use, and level of maintenance from the National Transit Database (NTD); the information used in this edition of the C&P report is from 2010. Age information is available on a vehicle-by-vehicle basis from the NTD and collected for all other assets through special surveys. Average maintenance expenditures and major

rehabilitation expenditures by vehicle are also available on agency and modal bases. For the purpose of calculating conditions, agency maintenance and rehabilitation expenditures for a particular mode are assumed to be the same average value for all vehicles operated by that agency in that mode. Because agency maintenance expenditures may fluctuate from year to year, TERM uses a 5-year average.

The deterioration schedules applied for track and guideway structures are based on special studies. The methods used to calculate deterioration schedules and the sources of the data on which deterioration schedules are based are discussed in Appendix C.

Condition estimates in each edition of the C&P report are based on contemporary updated asset inventory information and reflect updates in TERM's asset inventory data. Annual data from the NTD were used to update asset records for the Nation's transit vehicle fleets. In addition, updated asset inventory data were collected from 30 of the Nation's largest rail and bus transit agencies to support analysis of non-vehicle needs. Because these data are not collected annually, it is not possible to provide accurate time series analysis of non-vehicle assets. FTA is working to develop improved data in this area. Appendix C provides a more detailed discussion of TERM's data sources. *Exhibit 3-19* shows the distribution of asset conditions, by replacement value, across major asset categories for the entire U.S. transit industry.

Exhibit 3-19 Distribution of Asset Physical Conditions by Asset Type for All Modes



Source: Transit Economic Requirements Model.

Condition estimates for assets in this report are weighted by the replacement value of each asset. This takes into account the fact that assets vary substantially in replacement value. So, a $1-million railcar in poor condition is a much bigger problem than a $1-thousand turnstile in similar condition. As an example of the calculation involved, consider: the cost-weighted average of a $100 asset in condition 2 and a $50 asset in condition 4 would be (100x2+50x4)/(100+50) = 2.67. The un-weighted average would be (2+4)/2 = 3.

The Replacement Value of U.S. Transit Assets

The total replacement value of the transit infrastructure in the United States was estimated at $678.9 billion in 2010. These estimates, presented in *Exhibit 3-20*, are based on asset inventory information contained in TERM. The estimates are reported in 2010 dollars. They exclude the value of assets that belong to special service operators that do not report to the NTD. Rail assets totaled $547.6 billion, or roughly 80 percent of all transit assets. Non-rail assets were estimated at $120.5 billion. Joint assets totaled $10.8 billion; they consist of assets that serve more than one mode within a single agency and can include administrative facilities, intermodal transfer centers, agency communications systems (e.g., telephone, radios, and computer networks), and vehicles used by agency management (e.g., vans and automobiles).

Exhibit 3-20 Estimated Replacement Value of the Nation's Transit Assets, 2010

	Replacement Value (Billions of 2010 Dollars)			
Transit Asset	Nonrail	Rail	Joint Assets	Total
Maintenance Facilities	$59.8	$30.6	$5.4	$95.8
Guideway Elements	$12.1	$240.4	$1.0	$253.5
Stations	$3.7	$88.1	$0.6	$92.4
Systems	$3.0	$112.9	$3.3	$119.2
Vehicles	$41.9	$75.7	$0.5	$118.0
Total	**$120.5**	**$547.6**	**$10.8**	**$678.9**

Source: Transit Economic Requirements Model.

Bus Vehicles (Urban Areas)

Bus vehicle age and condition information is reported according to vehicle type for 2000 to 2010 in *Exhibit 3-21.* When measured across all vehicle types, the average age of the Nation's bus fleet has remained essentially unchanged since 2004. Similarly, the average condition rating for all bus types (calculated as the weighted average of bus asset conditions, weighted by asset replacement value) is also relatively unchanged, remaining near the bottom of the adequate range for the last decade. The percentage of vehicles below the state of good repair replacement threshold (condition 2.5) has remained in the range of 10 to 12 percent for this same time period. Note that while this observation holds across all vehicle types, the proportion of full-size buses (the vehicle type that supports most fixed-route bus services) declined from 15.2 percent in 2008 to 12.5 percent in 2010. This reduction likely reflects the preliminary impacts of transit-related American Recovery and Reinvestment Act (Recovery Act) spending, a significant proportion of which was expended on full-sized buses. It is expected that this proportion will be shown to have declined further as newer vehicle age data become available that reflect Recovery Act related bus vehicle procurements on or after 2010.

Exhibit 3-21 Urban Transit Bus Fleet Count, Age, and Condition, 2000–2010

	2000	2002	2004	2006	2008	2010
Articulated Buses						
Fleet Count	2,002	2,799	3,074	3,445	4,302	4,896
Average Age (Years)	6.6	7.2	5.0	5.3	6.3	6.5
Average Condition Rating	3.5	3.3	3.5	3.5	3.3	3.2
Below Condition 2.50 (Percent)	24.9%	16.6%	5.0%	2.1%	2.6%	3.7%
Full-Size Buses						
Fleet Count	46,380	46,573	46,139	46,714	45,985	45,441
Average Age (Years)	8.1	7.5	7.2	7.4	7.9	7.8
Average Condition Rating	3.2	3.2	3.2	3.2	3.1	3.1
Below Condition 2.50 (Percent)	14.5%	13.1%	12.3%	11.3%	15.2%	12.5%
Mid-Size Buses						
Fleet Count	7,203	7,269	7,114	6,844	7,009	7,218
Average Age (Years)	5.5	8.4	8.1	8.2	8.3	8.1
Average Condition Rating	3.4	3.1	3.1	3.1	3.1	3.1
Below Condition 2.50 (Percent)	8.3%	14.1%	13.2%	14.2%	12.4%	12.5%
Small Buses						
Fleet Count	8,646	14,857	15,972	16,156	19,366	19,493
Average Age (Years)	4.2	4.5	4.6	5.1	5.1	5.2
Average Condition Rating	3.6	3.4	3.5	3.4	3.4	3.4
Below Condition 2.50 (Percent)	2.2%	8.8%	10.1%	10.3%	11.6%	10.2%
Vans						
Fleet Count	14,583	17,147	18,713	19,515	26,823	28,531
Average Age (Years)	3.2	3.2	3.3	3.0	3.2	3.4
Average Condition Rating	3.8	3.7	3.8	3.8	3.8	3.7
Below Condition 2.50 (Percent)	0.2%	7.2%	6.7%	8.4%	8.0%	8.2%
Total Bus						
Total Fleet Count	78,814	88,645	91,012	92,674	103,485	105,579
Weighted Average Age (Years)	6.5	6.2	6.0	6.0	6.1	6.1
Weighted Average Condition Rating	3.3	3.2	3.3	3.3	3.1	3.0
Below Condition 2.50 (Percent)	10.2%	11.8%	10.6%	10.4%	12.0%	10.5%

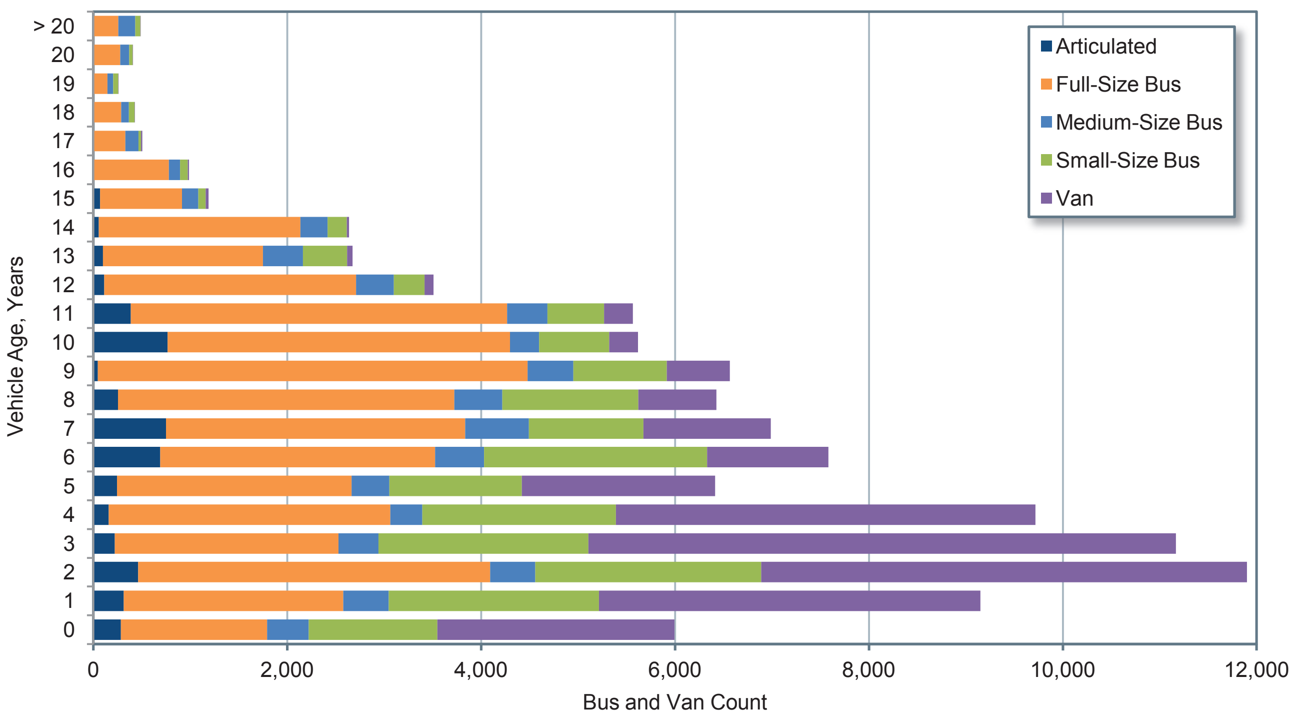
Sources: Transit Economic Requirements Model and National Transit Database.

The Nation's bus fleet has grown at an average annual rate of roughly 3 percent over the last decade, with most of this growth concentrated in three vehicle types including: large, 60-foot articulated buses; small buses of under 25 feet (frequently dedicated to flexible route bus services); and vans. The large increase in the number of vans reflects both the needs of an aging population (paratransit services) and an increase in the popularity of vanpool services. In contrast, the number of full- and medium-sized buses has remained relatively flat since 2000.

Similarly, *Exhibit 3-22* presents the age distribution of the Nation's transit buses and vans. Note here that full-size buses and vans account for the highest proportion (roughly 70 percent) of the Nation's rubber tire transit vehicles. Moreover, while most vans are retired by age 6 and most buses by age 15, roughly 5 to 10 percent of these fleets remain in service well after their typical retirement ages.

Furthermore, it appears the economic recession had an impact on the purchase of new vehicles and, thus, the age profile of buses and vans at transit agencies in the Nation. The peak of the age distribution reflects vehicles 2 years old, i.e., those purchased between July 1, 2007, and June 30, 2008. Purchases declined in the 2 years following that period.

Exhibit 3-22 Age Distribution of Buses and Vans, 2010



Source: Transit Economic Requirements Model and National Transit Database.

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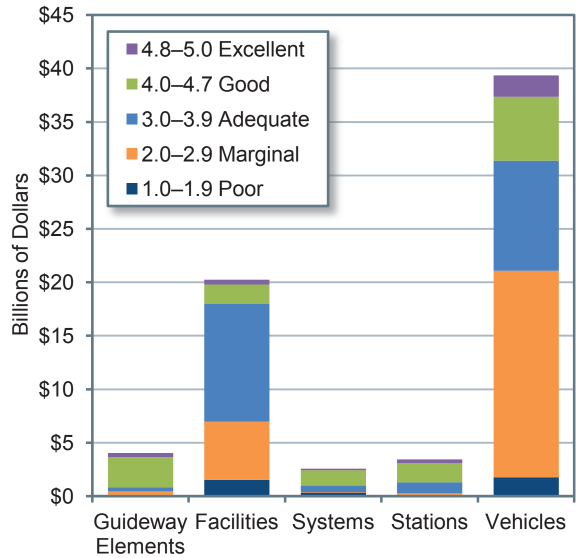
Other Bus Assets (Urban Areas)

The more comprehensive capital asset data described above allow us to report a more complete picture of the overall condition of bus-related assets. *Exhibit 3-23* shows TERM estimates of current conditions for the major categories of fixed-route bus assets. Vehicles constitute roughly half of all fixed-route bus assets and maintenance facilities make up another third. Roughly one-third of bus maintenance facilities are rated below condition 3.0, compared to roughly one-half for bus, paratransit, and vanpool vehicles.

Exhibit 3-23 Distribution of Estimated Asset Conditions by Asset Type for Bus



Source: Transit Economic Requirements Model.

Rail Vehicles

The NTD collects annual data on all rail vehicles; this data is shown in *Exhibit 3-24* broken down by the major categories of rail vehicle. Measured across all rail vehicle types, the average age of the Nation's rail fleet has remained essentially unchanged, averaging between 19 to 20 years since 2004. The average condition of all rail vehicle types (calculated as the weighted average of vehicle conditions, weighted by vehicle replacement cost) is also relatively unchanged, remaining near 3.5 since 2000. The percentage of vehicles below the state of good repair replacement threshold (condition 2.5) has remained in the range of 3.6 to 4.6 percent since 2002. Note that, although this observation holds across all vehicle types, the analysis suggests that the majority of lower condition vehicles are found in the light and heavy rail fleets. It should be noted, however, that the majority of light rail vehicles with an estimated condition of less than 2.5 are historic street cars and trolley cars with an average age of 75 years. Given their historic vehicle status, the estimated condition of these vehicles (driven primarily by age) should be viewed as a fairly rough approximation.

During the period from 2000 to 2010, the Nation's rail transit fleet grew at an annual average rate of roughly 2.0 percent, with this rate of growth largely determined by the rate of increase in the heavy rail fleet (which represents just over half of the total fleet and which grew at an average annual rate of 1.5 percent over this time period). In contrast, the annual rate of increase in commuter rail and light rail fleets has been appreciably higher, averaging roughly 3.1 percent and 5.2 percent, respectively. This reflects recent rail transit investments in small- and medium-sized urban areas whose size and density do not justify the greater investment needed for heavy rail construction.

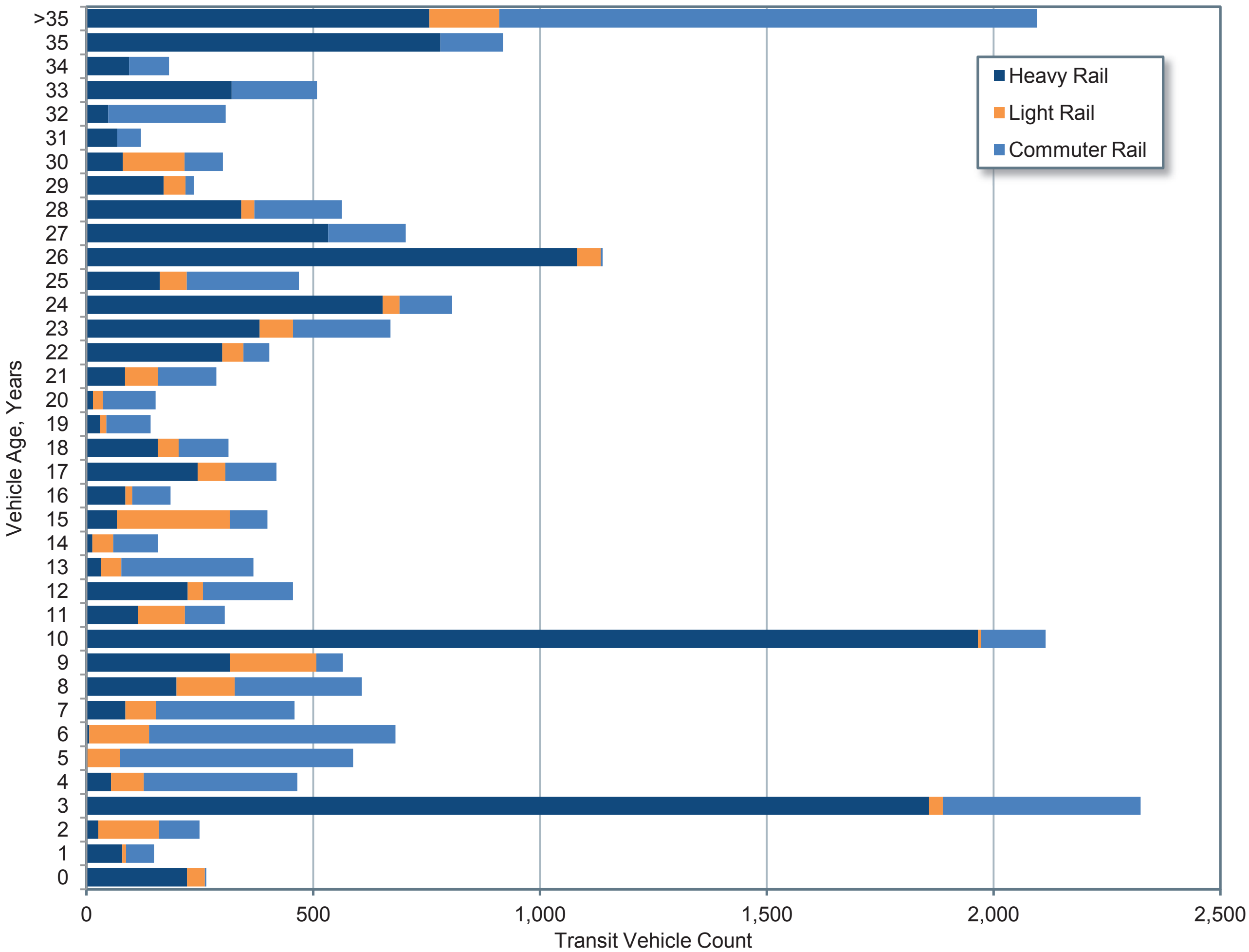
Exhibit 3-24 Urban Transit Rail Fleet Count, Age, and Condition, 2000–2010

	2000	2002	2004	2006	2008	2010
Commuter Rail Locomotives						
Fleet Count	576	709	710	740	790	822
Average Age (Years)	15.2	17.2	17.8	16.7	19.6	19.4
Average Condition Rating	4.5	3.7	3.7	4.0	3.6	3.6
Below Condition 2.50 (Percent)	5.7%	0.0%	0.0%	0.0%	0.0%	0.0%
Commuter Rail Passenger Coaches						
Fleet Count	2,743	2,985	3,513	3,671	3,539	3,711
Average Age (Years)	17.5	19.2	17.7	16.8	19.9	19.1
Average Condition Rating	4.3	3.7	3.8	4.1	3.6	3.7
Below Condition 2.50 (Percent)	10.8%	0.0%	0.0%	0.0%	0.0%	0.0%
Commuter Rail Self-Propelled Passenger Coaches						
Fleet Count	2,466	2,389	2,470	2,933	2,665	2,659
Average Age (Years)	25.2	27.1	23.6	14.7	18.9	19.7
Average Condition Rating	4.1	3.5	3.7	3.8	3.7	3.7
Below Condition 2.50 (Percent)	4.1%	0.0%	0.0%	0.0%	0.0%	0.0%
Heavy Rail						
Fleet Count	10,028	11,093	11,046	11,075	11,570	11,648
Average Age (Years)	23.1	19.8	19.8	22.3	21.0	18.8
Average Condition Rating	3.2	3.4	3.4	3.3	3.3	3.4
Below Condition 2.50 (Percent)	4.8%	6.1%	5.6%	5.5%	6.1%	5.2%
Light Rail						
Fleet Count	1,335	1,637	1,884	1,832	2,151	2,222
Average Age (Years)	15.8	17.9	16.5	14.6	17.1	18.1
Average Condition Rating	3.6	3.5	3.6	3.7	3.6	3.5
Below Condition 2.50 (Percent)	8.4%	11.8%	9.3%	6.4%	7.1%	6.9%
Total Rail						
Total Fleet Count	17,148	18,813	19,623	20,251	20,715	21,062
Weighted Average Age (Years)	21.7	20.4	19.5	19.3	20.1	18.9
Weighted Average Condition Rating	3.5	3.5	3.5	3.6	3.5	3.5
Below Condition 2.50 (Percent)	6.0%	4.6%	4.1%	3.6%	4.2%	3.6%

Sources: Transit Economic Requirements Model and National Transit Database.

Similarly, *Exhibit 3-25* presents the age distribution of the Nation's rail transit vehicles, emphasizing that heavy rail vehicles account for more than one-half of the Nation's rail fleet whereas light rail, a mode typically found in smaller rail markets, only accounts of 10 percent of rail vehicles. At the same time, roughly one-third of rail and commuter vehicles are more than 25 years old—with close to 2,000 heavy and commuter rail vehicles exceeding 35 years in age. It is instructive to compare the results in *Exhibit 3-25* with the age distribution of transit buses and vans in *Exhibit 3-22;* while the latter show a comparatively clear pattern of preferred retirement age by bus and van vehicle type, this pattern is absent from the rail vehicle results.

Exhibit 3-25 Age Distribution of Rail Transit Vehicles, 2010



Source: Transit Economic Requirements Model and National Transit Database.

Other Rail Assets

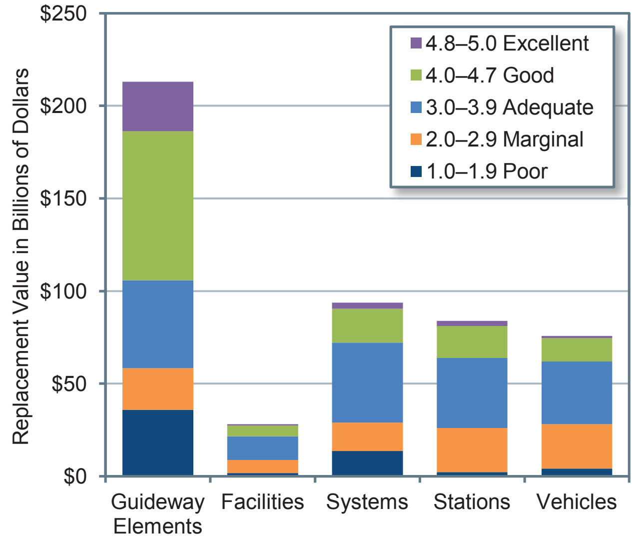
Non-vehicle transit rail assets can be divided into four general categories: guideway elements, facilities, systems, and stations. TERM estimates of the condition distribution for each of these categories are shown in *Exhibit 3-26*.

The largest category by replacement value is guideway elements. These consist of tracks, ties, switches, ballasts, tunnels, and elevated structures. The replacement value of this category is $213.0 billion, of which $35.8 billion is rated below condition 2.0 (17 percent) and $22.6 billion is rated between condition 2.0 and 3.0. The relatively large proportion of guideway and systems assets that are rated below condition 2.0 and the magnitude of the $49.5-billion investment required to replace them represent major challenges to the rail transit industry. Although maintaining these assets is one of the largest expenses associated with operating rail transit, FTA does not collect detailed data on these elements, in part because they are hard to break down into discrete sections that have common life expectancies. Service life for track, for example, is highly dependent on the amount of use and on location factors.

Systems, which consist of power, communication, and train control equipment, represent the next largest category. These assets have a replacement value of $93.6 billion, of which $13.7 billion is rated below condition 2.0 (19 percent) and $15.3 billion is rated between condition 2.0 and 3.0. This is another category where many assets are difficult to characterize according to standard types and life expectancies. As a result, FTA has only limited data from which to make needs projections.

Stations have a replacement value of $83.8 billion with only $2.3 billion rated below condition 2.0 and $23.8 billion rated between condition 2.0 and 3.0. Facilities, mostly consisting of maintenance and administration buildings, have a replacement value of $28.1 billion with $1.8 billion rated below condition 2.0 and $7.0 billion rated between condition 2.0 and 3.0.

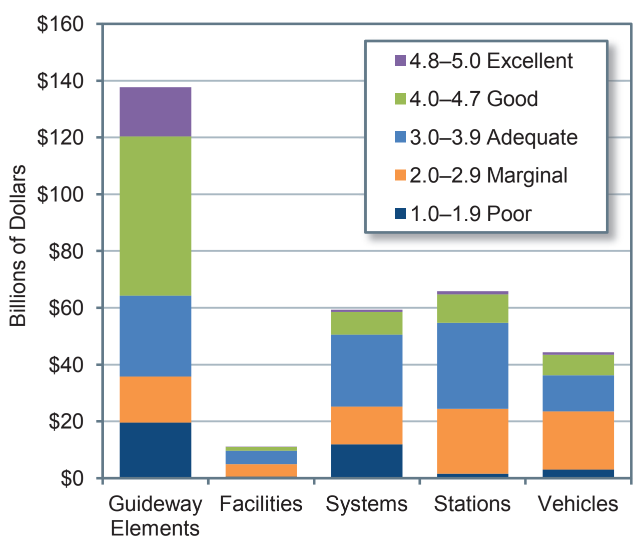
Exhibit 3-26 **Distribution of Asset Physical Conditions by Asset Type for All Rail**



Source: Transit Economic Requirements Model.

Rail transit consists of heavy rail (urban dedicated guideway), light rail (in mixed traffic), and commuter rail (suburban passenger rail) modes. Almost half of rail transit vehicles are in heavy rail systems. Heavy rail represents $318 billion (64 percent) of the total transit rail replacement cost of $547.6 billion. Some of the Nation's oldest and largest transit systems are served by heavy rail (Boston, New York, Washington, San Francisco, Philadelphia, and Chicago). The condition distribution of heavy rail assets, which represent the largest share of U.S. rail transit assets, is shown in *Exhibit 3-27*.

Exhibit 3-27 **Distribution of Asset Physical Conditions by Asset Type for Heavy Rail**



Source: Transit Economic Requirements Model.

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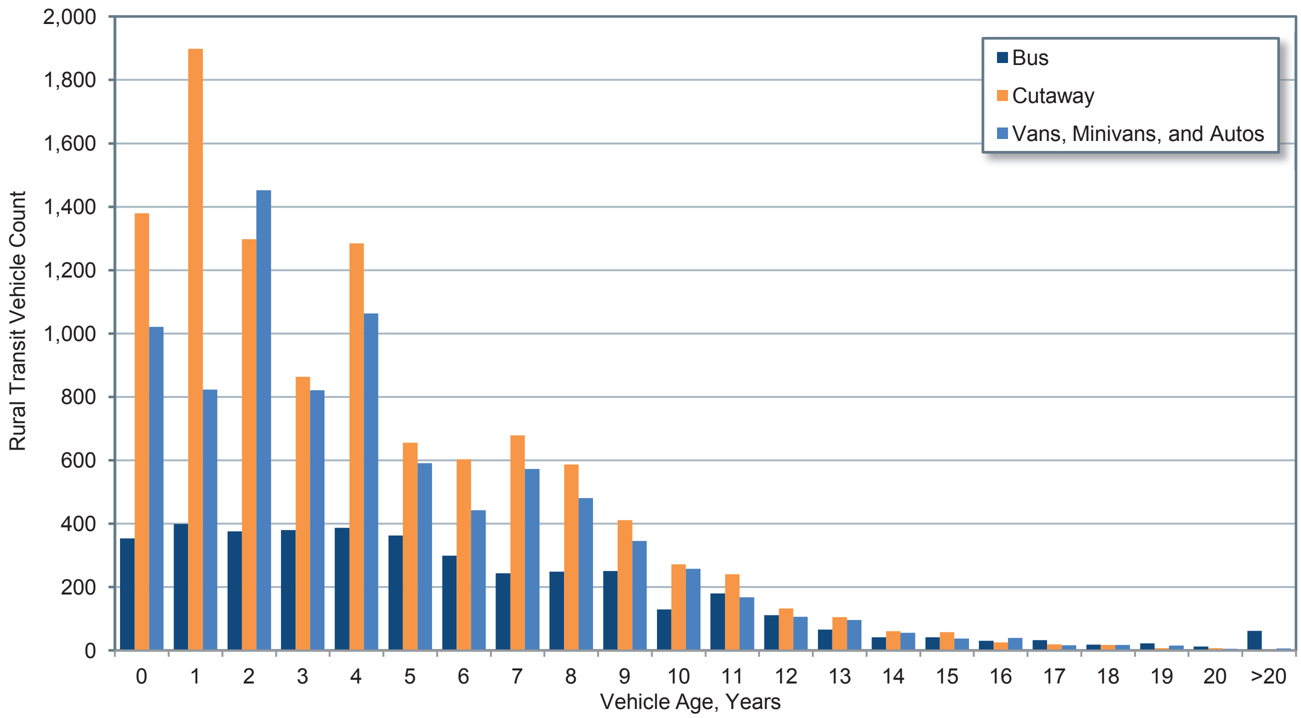
Rural Transit Vehicles and Facilities

All transit vehicles owned by rural systems are buses, vans, or other small passenger vehicles (see Chapter 2). Data on the number and age of rural vehicles and the number of maintenance facilities is now collected in the NTD, allowing FTA to report more accurately on rural transit conditions and on the 682 rural maintenance facilities that were reported. The age distribution of rural transit vehicles is summarized in *Exhibit 3-28*.

For 2010, data reported to the NTD indicated that 8.1 percent of rural buses, 18.4 percent of cutaways, and 38.6 percent of rural vans were past their FTA minimum life expectancy (12 years for buses, 7 to 10 for cutaways, and 4 for vans). The rural transit fleet had an average age of 4.5 years in 2010; buses, with an average age of 5.9 years, were older than vans and cutaways, which had an average age of 4.1 years and 4.4 years, respectively. Overall, 33.3 percent of the U.S. fleet was more than 5 years old.

Exhibit 3-28 **Age Distribution of Rural Transit Vehicles, 2010**



Source: Transit Economic Requirements Model and National Transit Database.

CHAPTER 4

Safety

Highway Safety

Every agency within the U.S. Department of Transportation (DOT) is concerned with safety; however, three operating administrations have specific responsibilities for addressing highway safety. The Federal Highway Administration (FHWA) focuses on infrastructure safety design and operations. The National Highway Traffic Safety Administration (NHTSA) has responsibility for overseeing vehicle safety standards and administering driver behavior programs. The Federal Motor Carrier Safety Administration (FMCSA) has the mission to reduce crashes, injuries, and fatalities involving large trucks and buses. This section describes the safety of the Nation's highway system, with a focus on roadway factors and programs administered by FHWA.

Statistics in this section are primarily drawn from the Fatality Analysis Reporting System (FARS). FARS is maintained by NHTSA, which has a cooperative agreement with States to provide information on fatal crashes. FARS is a nationwide census providing DOT, Congress, and the American public data regarding fatal motor vehicle traffic crashes. Safety statistics in this section were compiled in early 2012 and represent a "snapshot in time" during the preparation of this report, which is why they may not precisely correspond to other reports completed during the past year.

In addition to examining the progress of safety efforts to date, FHWA continues to pursue opportunities to improve safety programming. One example of this is FHWA's work within DOT and with appropriate stakeholders to prepare for the transition to a performance-based management framework for the Federal Highway Program. Transportation Performance Management will support the decision making process, increase accountability and oversight of the Federal-Aid Program, and inform the public on the condition and performance of the Nation's highway transportation system. The safety performance area is well positioned for performance management because FARS is a highly credible, broadly accepted national data source. The National Center for Statistics and Analysis at NHTSA also estimates serious injuries nationally through the National Automotive Sampling System General Estimates System. These national data sets offer a statistically produced annual estimate of the total number of serious injury crashes.

2010 FARS Update

Recently, the Fatality Analysis Reporting System (FARS) and the National Automotive Sampling System General Estimates System (NASS GES) underwent a standardization effort. The effort began in 2006 and the second phase was implemented in the 2010 data-collection year. The definition and element attribute changes introduced in 2010 are the most substantive and most numerous 1-year changes in these systems.

Probably the most notable changes were the introduction of precrash information in FARS (already collected in NASS GES) and a change to how the groups of related data elements are organized. The precrash information represents not only a new coding form, but also, more important, a largely new concept for FARS: attempting to collect data about the conditions, events, and driver actions that preceded and may have contributed to the crash. Precrash data are intended to improve crash avoidance research and have been included in NASS GES since 1992. The new FARS Precrash form information consists of 23 data elements, nine of which were previously coded at the Crash level, three each at the Vehicle and Driver levels, and eight new elements. These elements provide details about the characteristics of the roadway selected for each vehicle.

The final phase of the FARS/NASS GES standardization will occur during the 2011 data collection year, at which point FARS and NASS GES, while remaining separate data systems, will share a single data-entry system and uniform set of data elements.

FHWA also recognizes that data are critical to the success of any highway safety program because data support problem identification, program development and implementation, evaluation, and performance

management. The Roadway Safety Data Program (RSDP) is a collaborative effort between FHWA and States to ensure that they are best able to develop robust data-driven safety capabilities. The RSDP focuses on four areas: collection, analysis, management, and expandability/linkability.

In 2011 and 2012, the RSDP State Roadway Safety Data Capability Assessment project assessed the capability level of each State's roadway safety data program. With participation from all 50 States and the District of Columbia, this project is a cornerstone for data improvement efforts at both the State and national levels. In addition to the results from the assessment, each State also receives an action plan outline to help them work toward improving their roadway safety data capabilities. Additionally, a national gap analysis and action plan will be developed based on common themes and identified needs across the States.

Overall Fatalities and Injuries

There were more than 5.2 million police-reported motor vehicle crashes in the United States in 2010. Fewer than 1 percent (0.6 percent or 30,196) of these crashes were severe enough to result in a fatality, while 27.9 percent (approximately 1.45 million) resulted in injuries and 71.5 percent (approximately 3.72 million) resulted in property damage without injury, as shown in *Exhibit 4-1*. The total economic cost of crashes in the United States was estimated at $230.6 billion in 2000. Motor vehicle crashes cost U.S. society an estimated $7,300 per second. These costs include medical-related costs, market and household productivity, insurance administration, workplace costs, legal costs, travel delay, and property damage. More information on the cost of crashes can be found in NHTSA's report *Economic Impact of Motor Vehicle Crashes 2000*.

Exhibit 4-1 **Crashes by Severity, 2000–2010**

	Crash Severity							
	Fatal		Injury		Property Damage Only		Total Crashes	
Year	Number	Percent	Number	Percent	Number	Percent	Number	Percent
2000	37,526	0.6	2,024,840	34.1	3,876,303	65.3	5,938,669	100.0
2001	37,862	0.6	1,949,680	32.0	4,100,041	67.4	6,087,583	100.0
2002	38,491	0.6	1,872,498	30.8	4,172,434	68.6	6,083,423	100.0
2003	38,477	0.6	1,869,084	30.7	4,174,298	68.6	6,081,859	100.0
2004	38,444	0.6	1,789,046	30.0	4,126,283	69.3	5,953,773	100.0
2005	39,252	0.7	1,753,835	29.6	4,132,826	69.7	5,925,913	100.0
2006	38,648	0.7	1,677,165	29.3	4,007,220	70.0	5,723,033	100.0
2007	37,435	0.6	1,651,565	28.6	4,076,939	70.7	5,765,939	100.0
2008	34,172	0.6	1,573,910	28.3	3,953,040	71.1	5,561,122	100.0
2009	30,862	0.6	1,460,500	27.7	3,782,288	71.7	5,273,650	100.0
2010	30,196	0.6	1,452,378	27.9	3,724,801	71.5	5,207,375	100.0

Source: Fatality Analysis Reporting System/National Center for Statistics and Analysis, NHTSA.

Exhibit 4-2 describes the considerable improvement in highway safety since Federal legislation first addressed the issue in 1966. In 1966, there were 50,894 traffic deaths. Fatalities reached their highest point in 1972 with 54,589 fatalities, then declined sharply to 39,250 fatalities in 1992; the implementation of a national speed limit is believed to have contributed to this decline. Between 1992 and 2006, there was more limited progress in reducing the number of fatalities. The number of fatalities generally increased year to year from 1992 (39,250 fatalities) to 2006 (42,708 fatalities). However, in 2010, a record low number of fatalities occurred (32,885), the lowest number in the post-1966 era.

Fatality rate per vehicle miles traveled (VMT) provides a metric that allows transportation professionals to consider fatalities in terms of the additional exposure associated with driving more miles. In 1966, the

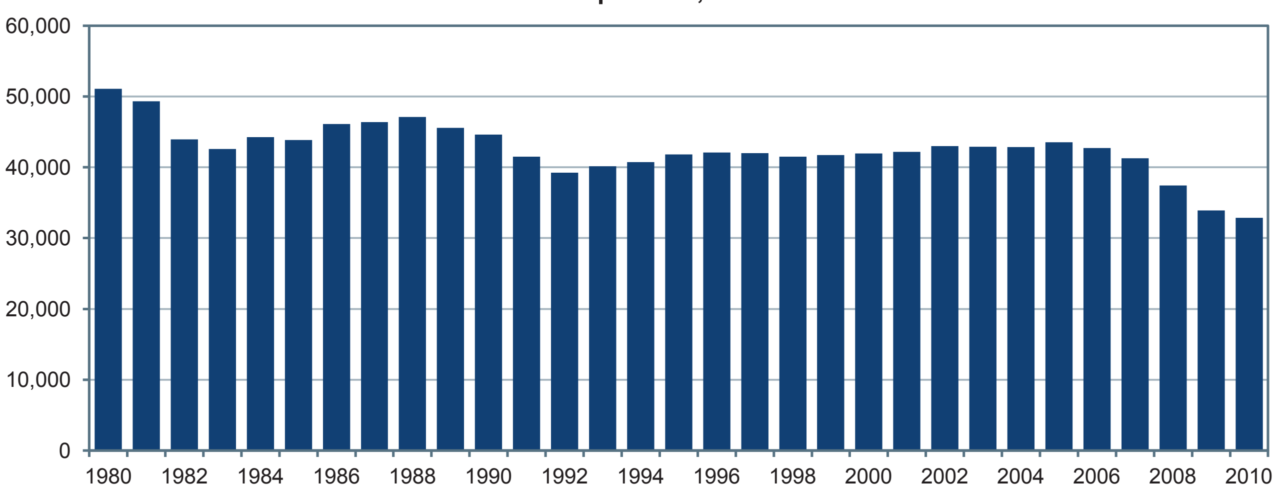
Exhibit 4-2 **Summary of Fatality and Injury Rates, 1966–2010**

Year	Fatalities	Resident Population (Thousands)	Fatalities per 100,000 Population	Licensed Drivers (Thousands)	Fatalities per 100 Million VMT	Injured	Injuries per 100,000 Population	Injuries per 100 Million VMT
1966	50,894	196,560	25.89	100,998	5.50			
1968	52,725	200,706	26.27	105,410	5.20			
1970	52,627	205,052	25.67	111,543	4.74			
1972	54,589	209,896	26.01	118,414	4.30			
1974	45,196	213,854	21.13	125,427	3.50			
1976	45,523	218,035	20.88	134,036	3.25			
1978	50,331	222,585	22.61	140,844	3.26			
1980	51,091	227,225	22.48	145,295	3.35			
1982	43,945	231,664	18.97	150,234	1.76			
1984	44,257	235,825	18.77	155,424	2.57			
1986	46,087	240,133	19.19	159,486	2.51			
1988	47,087	244,499	19.26	162,854	2.32	3,416,000	1,397	169
1990	44,599	249,439	17.88	167,015	2.08	3,231,000	1,295	151
1992	39,250	254,995	15.39	173,125	1.75	3,070,000	1,204	137
1994	40,716	260,327	15.64	175,403	1.73	3,266,000	1,255	139
1996	42,065	265,229	15.86	179,539	1.69	3,483,000	1,313	140
1998	41,501	270,248	15.36	184,861	1.58	3,192,000	1,181	121
2000	41,945	281,422	14.90	190,625	1.53	3,077,580	1,094	112
2002	43,005	288,369	14.91	194,296	1.51	2,813,502	976	99
2004	42,836	293,655	14.59	198,889	1.45	2,652,710	903	90
2006	42,708	299,398	14.26	202,810	1.42	2,453,369	819	81
2008	37,423	304,060	12.31	208,321	1.26	2,250,357	740	76
2009	33,883	307,007	11.04	209,618	1.15	2,117,613	690	72
2010	32,885	309,350	10.63	210,115	1.11	2,105,030	680	71

Source: Fatality Analysis Reporting System/National Center for Statistics and Analysis, NHTSA.

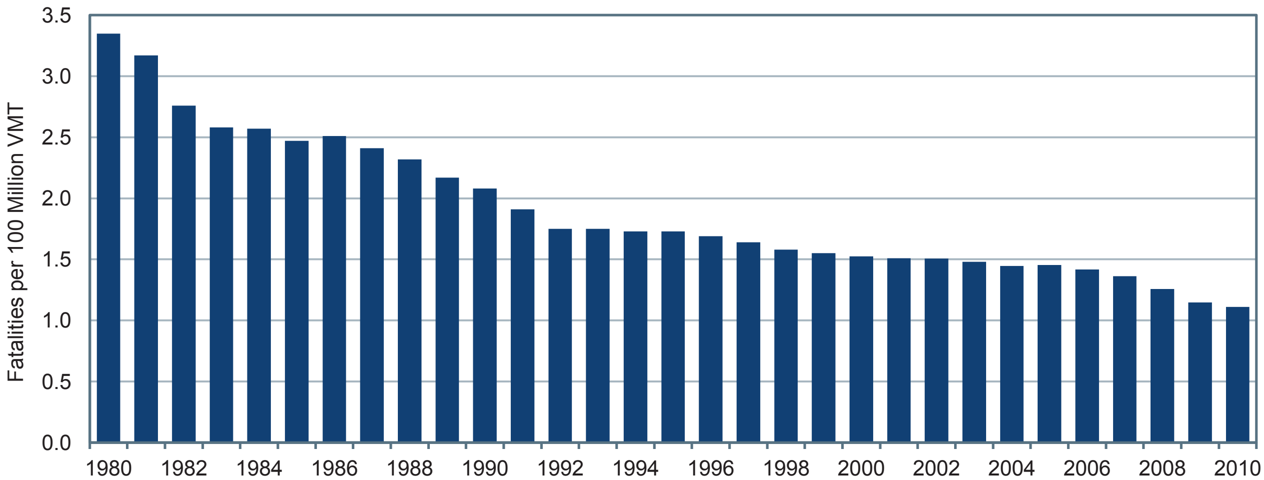
fatality rate was 5.50 fatalities per 100 million VMT. By 2010, the fatality rate had declined to 1.11 per 100 million VMT. *Exhibit 4-3* and *Exhibit 4-4* compare the number of fatalities with fatality rates per VMT between 1980 and 2010. It is also worth noting that the number of fatalities decreased by 23 percent

Exhibit 4-3 **Fatalities Related to Motor Vehicle Operation, 1980–2010**



Source: Fatality Analysis Reporting System/National Center for Statistics and Analysis, NHTSA.

Exhibit 4-4 **Fatality Rates, 1980–2010**



Source: Fatality Analysis Reporting System/National Center for Statistics and Analysis, NHTSA.

between 2006 and 2010, coinciding with the timing of the implementation of FHWA's Highway Safety Improvement Program.

Between 1990 and 2010, the overall number of fatalities dropped by more than 26 percent and the overall number of traffic-related injuries decreased by almost 35 percent (from 3.2 million to 2.1 million). Injuries increased between 1992 and 1996, but have steadily declined since then. In 1990, the injury rate was 151 per 100 million VMT; by 2010, the number had dropped (by almost 53 percent) to 71 per 100 million VMT.

Highway Fatalities: Roadway Contributing Factors

When a crash occurs, it is generally the result of numerous contributing factors. Roadway, driver, weather, and vehicle factors all have an impact on the safety of the Nation's highway system. Though FHWA focuses on roadway factors, it also recognizes the importance of collaborating with other agencies to better understand the relationship between all three areas of contributing factors and to address cross-cutting ones.

FHWA has three focus areas related to the roadway reduction of crashes: roadway departures, intersection, and pedestrian crashes. These three focus areas have been selected because they account for a noteworthy portion of overall fatalities and represent an opportunity to significantly impact the overall number of fatalities and serious injuries. In 2010, roadway departure, intersection, and pedestrian fatalities accounted for 52.9 percent, 20.3 percent, and 13.0 percent of all crash fatalities, respectively. *Exhibit 4-5* shows data for these crash types between 2000 and 2010.

Focus Area Safety Programs

These categories are not mutually exclusive; the fatalities shown in *Exhibit 4-5* can involve a combination of factors—intersection- and pedestrian-related, for example—so that some fatalities appear in more than one category. Because of this interdependence, FHWA has developed two programs that are targeted at collaborative and comprehensive efforts to address these areas.

First, the Focused Approach to Safety Program works to better address the most critical safety challenges by devoting additional efforts to high-priority States and targeting technical assistance and resources. After an evaluation in 2010, eligibility criteria were revised and lessons learned were incorporated to improve the program.

Exhibit 4-5 Highway Fatalities by Crash Type, 2000–2010

	2000	2002	2004	2006	2008	2010	Percent Change 2010 to 2000
Roadway Departures[1, 2]	23,046	25,415	22,340	22,665	19,878	17,389	-24.5%
Intersection-Related[1,3]	8,689	9,273	9,176	8,850	7,809	6,758	-22.2%
Pedestrian-Related[1]	4,763	4,851	4,675	4,795	4,414	4,280	-10.1%

[1] *Some fatalities may overlap; for example, some intersection-related fatalities may involve pedestrians.*
[2] *Definition for roadway departure crashes was modified beginning in 2004.*
[3] *Definition for Intersection crashes was modified beginning in 2010.*

Source: Fatality Analysis Reporting System/National Center for Statistics and Analysis, NHTSA.

Second, in January 2012, FHWA issued a "Guidance Memorandum on Promoting the Implementation of Proven Safety Countermeasures." This guidance takes into consideration the latest safety research to advance a group of countermeasures that have shown great effectiveness in improving safety. The nine countermeasures are targeted to address three focus areas: Roadway Departure Safety, Intersection Safety, and Pedestrian Safety. This combined approach is designed to provide consistency in safety programming, and to target limited resources to problem areas and safety countermeasures that are likely to yield the greatest results in reducing the number of crash-related fatalities and injuries.

Roadway Departures

In 2010, there were 17,389 roadway departure fatalities; this accounts for 52.9 percent of all fatalities. A roadway departure crash is defined as a non-intersection crash which occurs after a vehicle crosses an edge line or a center line, or otherwise leaves the traveled way. In some cases, a vehicle crossed the centerline

Roadway Departure Focus States and Countermeasures

FHWA currently offers roadway departure technical assistance to State highway agencies that have a particularly high number of roadway departure fatalities in the form of crash data analysis and implementation plan development. Roadway Departure Implementation Plans have been developed for Kentucky, North Carolina, Oregon, South Carolina, and Tennessee, with additional State plans for Louisiana, California, and Arizona at various stages of development. Each plan is designed to address State-specific roadway departure safety issues on both State and local roadways to the extent that relevant data can be obtained and as is appropriate based on consultation with State and local agencies and the FHWA Division Office.

FHWA works with participating roadway departure focus States to develop individual data analysis packages focused on crash history and roadway attributes, and identify a set of strategies that can be used to reduce roadway departure crashes. Using a systemic approach, the plans identify a set of cost-effective countermeasures, deployment levels, and funding needs to reduce the number and severity of roadway departure crashes in the State by a target amount consistent with Strategic Highway Safety Plan goals. The final plan quantifies the costs and benefits of a roadway departure-focused initiative and provides a step-by-step process for implementation.

Three proven safety countermeasures for reducing roadway departure crashes are:

- Longitudinal rumble strips and stripes on two-lane rural roads – Milled or raised elements on the pavement intended to alert inattentive drivers through vibration and sound that their vehicles have left the travel lane
- Enhanced delineation and friction for horizontal curves – Signs and pavement designed to warn the driver in advance of the curve, with pavement friction critical for changing a vehicle's direction and ensuring that it remains in its lane
- Safety Edge – Technology that shapes the edge of a paved roadway in a way that eliminates tire scrubbing, a phenomenon that contributes to losing control of a vehicle (see Chapter 12 for additional discussion of this technology).

and struck another vehicle, hitting it head-on or sideswiping it. In other cases, the vehicle left the roadway and struck one or more man-made or natural objects, such as utility poles, embankments, guardrails, trees, or parked vehicles.

Intersections

Of the 32,885 fatalities that occurred in 2010, about 20.3 percent (6,673) occurred at intersections, of which 38.3 percent were rural and 61.7 percent were urban, as shown in *Exhibit 4-6*.

There are more than 3 million intersections in the United States, both signalized (e.g., those controlled by traffic signals) and nonsignalized (e.g., those controlled by stop or yield signs); and many factors may contribute to unsafe conditions at these areas. Road designs or traffic signals may need to be upgraded to account for current traffic levels. Approximately one-third of signalized intersection fatalities (2,224 fatalities) involve red-light running, which indicates a need to raise enforcement in this area.

Exhibit 4-6 Intersection-Related Fatalities by Functional System, 2010

	Fatalities	
	Count	Percent of Total
Rural Areas (under 5,000 in population)		
Principal Arterials	706	10.6%
Minor Arterials	554	8.3%
Collectors (Major and Minor)	765	11.5%
Locals	530	7.9%
Subtotal Rural Areas	**2,555**	**38.3%**
Urban Areas (5,000 or more in population)		
Principal Arterials	1,840	27.6%
Minor Arterials	1,086	16.3%
Collectors (Major and Minor)	290	4.3%
Locals	902	13.5%
Subtotal Urban Areas	**4,118**	**61.7%**
Total Highway Fatalities*	**6,673**	**100.0%**

** Total excludes 85 intersection-related fatalities not identified by functional class.*

Source: Fatality Analysis Reporting System/ National Center for Statistics and Analysis, NHTSA.

Intersection Focus States and Countermeasures

Intersection Focus States are eligible based on their average number of intersection fatalities over a 3-year period. In addition, FHWA considers the urban and rural roadway percentages within these States and the ratio of their actual intersection fatality rate versus the expected intersection fatality rate per VMT based on national urban and rural rates.

FHWA recognizes that, although a number of States have identified intersection safety as an emphasis area in their Strategic Highway Safety Plans (SHSPs), they may not have implementation plans to guide their intersection safety implementation activities on State and local roads. As part of the Focused Approach to Safety, FHWA works with States to develop Intersection Safety Implementation Plans (ISIPs). Using a systemic approach, these ISIPs include the specific activities, countermeasures, strategies, deployment levels, implementation steps, and estimates of funds necessary to achieve the intersection component of a State's SHSP goals. FHWA is also providing assistance to those States through webinars, technical assistance, and training courses.

FHWA is promoting three proven countermeasures associated specifically with intersection safety:

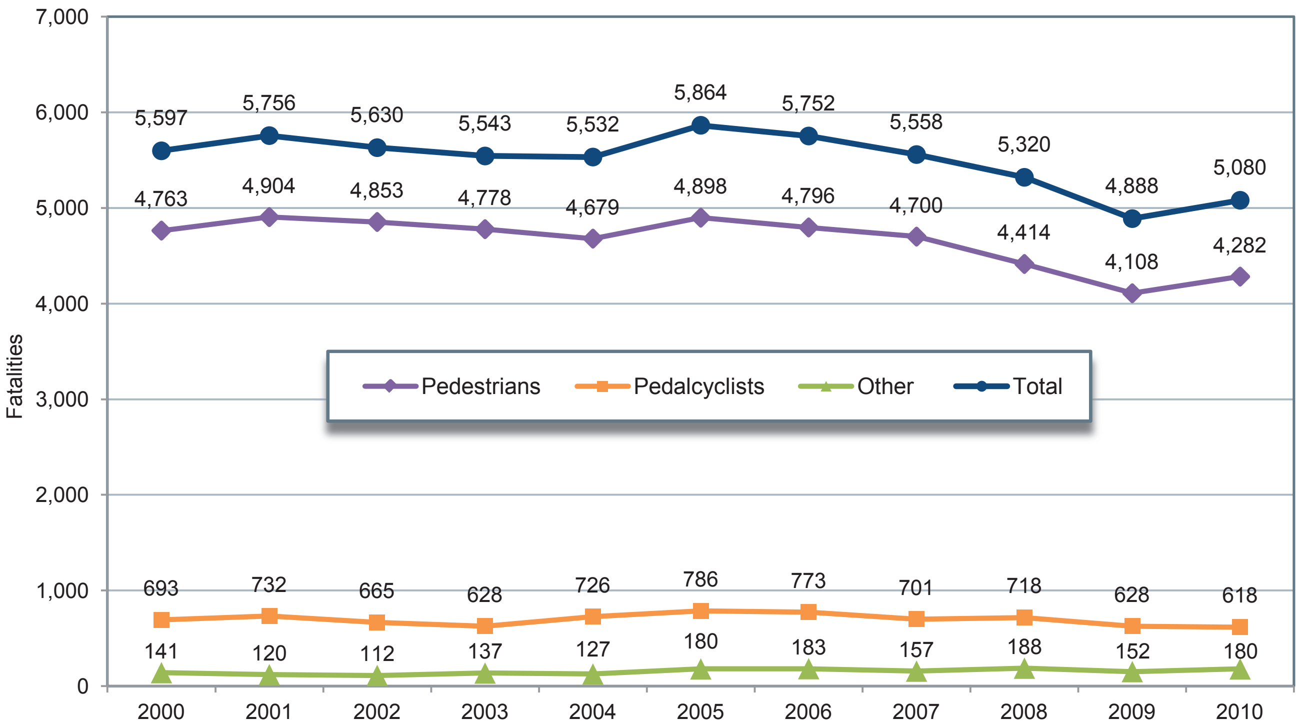
- Roundabouts – Modern type of circular intersection defined by a set of specific operational principles designed to create a low-speed environment, high operational performance, and a reduction of conflict points
- Corridor access management – Set of techniques that can be used to control access to highways, major arterials, and other roadways and that result in improved movement of traffic, reduced crashes, and fewer vehicle conflicts
- Backplates with retroreflective border – Added to traffic signals to improve the visibility of the illuminated face of the signal.

In addition, two of the countermeasures being promoted for pedestrian safety can also improve intersection safety: pedestrian hybrid beacons and road diets. Additional information on the benefits of countermeasures can be found at http://safety.fhwa.dot.gov/provencountermeasures/.

Pedestrians and Other Nonmotorists

Exhibit 4-7 displays nonmotorist traffic fatalities that occurred between 2000 and 2010. For the purposes of this report, the term nonmotorist includes pedestrians, pedalcyclists (such as bicyclists), skateboarders, roller skaters, and others using forms of transportation that are not motorized.

Exhibit 4-7 Pedestrian and Other Nonmotorist Traffic Fatalities, 2000–2010



Source: Fatality Analysis Reporting System/National Center for Statistics and Analysis, NHTSA.

Pedestrian Safety Focus States and Countermeasures

For the pedestrian focus area, FHWA designates focus cities and focus States. Cities are eligible to participate as pedestrian focus cities based on the number of pedestrian fatalities or the pedestrian fatality rate per population over a three year period.

FHWA's Office of Safety is aggressively working to reduce pedestrian fatalities by providing resources to focus States and cities. The Focused Approach effort has helped raise awareness of pedestrian safety problems and draw attention and resources to generate momentum for addressing pedestrian issues. The Focused Approach has provided support in the form of course offerings, conference calls, Web conferences, data analysis, and technical assistance for development of Pedestrian Safety Action Plans, which help State and local officials determine where to begin addressing pedestrian safety issues.

The Focused Approach offers free technical assistance and training courses to each of the focus States and cities and free bi-monthly webinars on a comprehensive, systemic approach to preventing pedestrian crashes. Training is available at a cost to non-focus States and cities through the Pedestrian and Bicycle Information Center and is made available through the National Highway Institute.

FHWA is promoting three proven countermeasures associated specifically with pedestrian safety:

- Median and pedestrian crossing islands in urban and suburban areas – Improve safety benefits to both pedestrians and vehicles by providing an area of refuge at the mid-point of the roadway, enhancing pedestrian crossing visibility, and reducing the speed of vehicles approaching the crossing
- Pedestrian hybrid beacons – Pedestrian-activated warning device located on the roadside or on mast arms over midblock pedestrian crossings.
- Road diets: A classic roadway reconfiguration that involves converting an undivided four-lane roadway into three lanes made up of two through-lanes and a center two-way left turn lane.

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The number of nonmotorist fatalities decreased 9.2 percent, from 5,597 in 2000 to 5,080 in 2010. This represents the overall reduction from 2000 to 2010, but the 5,080 nonmotorists killed in 2010 is an increase over the 11-year low of 4,888 reached in 2009.

Since 2000, the number of pedestrians killed by motor vehicle crashes has decreased by 10.1 percent, from 4,763 to 4,282, and the number of pedalcyclists has decreased almost 10.8 percent, from 693 to 618. However, there is some fluctuation in pedalcyclist fatalities, with the highest number of pedalcyclist fatalities (726) between 2000 and 2010 being reported in 2005.

There are several fatal crash scenarios involving pedestrians and bicyclists that are more common than others. In 2010, over three-fourths (79 percent) of all pedestrian fatalities occurred at non-intersection locations. Pedestrian fatalities are also more common in urban areas (73 percent) than rural areas (27 percent), and males made up 69 percent of the total pedestrian fatalities. Bicyclist fatalities demonstrate similar trends. In 2010, bicyclist fatalities usually occurred at non-intersections (67 percent) and in urban areas (72 percent), and mostly involved males (86 percent). FHWA has developed resources to conduct both pedestrian- and bicyclist-focused road safety audits, which can be used to identify nonmotorist safety problems and recommend potential solutions, such as roadway lighting, median refuges, bike lanes, HAWK (or High-Intensity Activated Crosswalk beacon) signals, road diets, and other traffic calming strategies. A number of States and cities have adopted “complete streets” policies, which aim to safely accommodate all road users. Such policies help ensure that safe and convenient walking and bicycling networks are developed.

Fatalities by Roadway Functional Class

Exhibit 4-8 and *Exhibit 4-9* show the number of fatalities and fatality rates by rural and urban functional class between 2000 and 2010. (See Chapter 2 for functional class definitions.)

As shown in *Exhibit 4-8*, the absolute number of fatalities grew slightly between 2000 and 2004 and then declined to 32,885 deaths in 2010. During the period from 2000 to 2010, the number of fatalities on urban

Exhibit 4-8 Fatalities by Functional System, 2000–2010

Functional System	2000	2002	2004	2006	2008	2010	Percent Change 2010/2000
Rural Areas (under 5,000 in population)							
Interstate	3,254	3,298	3,227	2,887	2,422	2,119	-34.9%
Other Principal Arterial	4,917	4,894	5,167	4,554	4,395	3,962	-19.4%
Minor Arterial	4,090	4,467	5,043	4,346	3,507	3,009	-26.4%
Major Collector	5,501	6,014	5,568	5,675	5,084	4,162	-24.3%
Minor Collector	1,808	2,003	1,787	1,650	1,421	1,137	-37.1%
Local	4,414	5,059	4,162	4,294	4,060	3,526	-20.1%
Unknown Rural	854	161	225	240	98	111	-87.0%
Subtotal Rural	**24,838**	**25,896**	**25,179**	**23,646**	**20,987**	**18,026**	**-27.4%**
Urban Areas (5,000 or more in population)							
Interstate	2,419	2,482	2,602	2,663	2,300	2,110	-12.8%
Other Freeway and Expressway	1,364	1,506	1,673	1,690	1,538	1,233	-9.6%
Other Principal Arterial	4,948	5,124	4,847	5,447	4,504	4,247	-14.2%
Minor Arterial	3,211	3,218	3,573	3,807	3,128	2,928	-8.8%
Collector	1,001	1,151	1,385	1,513	1,256	1,061	6.0%
Local	2,912	3,497	3,290	3,622	3,461	2,951	1.3%
Unknown Urban	258	35	211	49	31	16	-93.8%
Subtotal Urban	**16,113**	**17,013**	**17,581**	**18,791**	**16,218**	**14,546**	**-9.7%**
Unknown Rural or Urban	994	96	76	271	218	313	-68.5%
Total Highway Fatalities	**41,945**	**43,005**	**42,836**	**42,708**	**37,423**	**32,885**	**-21.6%**

Source: Fatality Analysis Reporting System/National Center for Statistics and Analysis, NHTSA.

roads decreased from 16,113 to 14,546, a reduction of almost 10 percent. At the same time, the number of fatalities on rural roads decreased from 24,838 to 18,026, a reduction of more than 27 percent. In 2010, fatalities from urban crashes accounted for 44.2 percent of all fatalities, while those resulting from rural crashes accounted for almost 54.8 percent. As shown in *Exhibit 4-8*, about 1 percent of crashes were not classified as either urban or rural. The fatality rate also decreased on both urban and rural roads since 2000, due in part to a combination of safety countermeasures and programs introduced by U.S. DOT and State partners. Although some of the reduction in roadway fatalities may have been attributed to a decrease in VMT between 2007 and 2009, the number of fatalities continued to decrease between 2009 and 2010 even as VMT increased in those 2 years.

Exhibit 4-9 shows the fatality rates for every urban and rural functional system between 2000 and 2010. Urban Interstate highways were the safest functional system, with a fatality rate of 0.44 per 100 million VMT in 2010. Among urban roads, Interstate highways and other freeways and expressways recorded the sharpest declines in fatality rates during this 11-year period with an overall reduction of approximately 28 percent.

Exhibit 4-9 Fatalities by Functional System, 2000–2010 (per 100 Million VMT)

Functional System	2000	2002	2004	2006	2008	2010	Percent Change 2010/2000
Rural Areas (under 5,000 in population)							
Interstate	1.21	1.18	1.21	1.12	1.00	0.86	-28.7%
Other Principal Arterial	1.98	1.90	2.14	1.96	1.98	1.76	-11.2%
Minor Arterial	2.38	2.53	2.99	2.67	2.31	1.99	-16.3%
Major Collector	2.63	2.82	2.77	2.94	2.73	2.36	-10.2%
Minor Collector	3.12	3.26	2.97	2.84	2.58	2.14	-31.5%
Local	3.45	3.63	3.14	3.22	3.08	2.66	-23.0%
Subtotal Rural	**2.29**	**2.30**	**2.35**	**2.28**	**2.12**	**1.83**	-20.0%
Urban Areas (5,000 or more in population)							
Interstate	0.61	0.61	0.57	0.56	0.48	0.44	-27.6%
Other Freeway and Expressway	0.77	0.79	0.80	0.78	0.69	0.56	-27.5%
Other Principal Arterial	1.24	1.25	1.08	1.17	0.97	0.93	-25.1%
Minor Arterial	0.99	0.95	0.99	1.01	0.83	0.78	-21.0%
Collector	0.74	0.81	0.85	0.87	0.72	0.59	-20.6%
Local	1.24	1.46	1.29	1.36	1.28	1.09	-12.4%
Subtotal Urban	**0.97**	**0.98**	**0.93**	**0.95**	**0.82**	**0.73**	-24.4%
Total Highway Fatality Rate	**1.53**	**1.51**	**1.45**	**1.42**	**1.26**	**1.11**	**-27.5%**

Source: Fatality Analysis Reporting System/National Center for Statistics and Analysis, NHTSA.

The overall fatality rate decreased by 20.0 percent on rural roads between 2000 and 2010. Among rural roads, minor collectors and Interstate highways recorded the sharpest declines in fatality rates during this period. The fatality rate for rural minor collectors in 2010 was 31.5 percent lower than in 2000, and the fatality rate for rural Interstates also decreased by 28.7 percent in the same period. Despite the overall decrease in fatality rate on both urban and rural functional systems, rural roads are far more dangerous than their urban counterparts, evidenced by a fatality rate on rural roads that is 2.5 times higher than the fatality rate on urban roads. A number of factors collectively result in this rural road safety challenge, such as greater curvature and obstacles close to the roadway, greater potential for roadway departure, and higher levels of speeding on undivided roadways.

There have been notable decreases in the fatality rates for both rural and urban local roads since 2000, at 23.0 and 12.4 percent, respectively. However, the fatality rate for rural local roads in 2010 was more than three times higher than that for the safest rural functional system (Interstate). Similarly, the fatality rate for urban local roads was more than two times higher the fatality rate for the safest urban functional classification (Interstate). Addressing the challenges associated with non-Interstate roads can be made more difficult by the diversity of ownership; Interstate roads are maintained by the State while other roads may be maintained by the State or a variety of local organizations, including cities and counties.

Locally Owned Road Safety

There are more than 30,000 local agencies that own and operate more than 75 percent of the Nation's roadways. Agency practitioners have varying levels of transportation safety expertise and often perform several duties in addition to transportation safety. The FHWA developed the workshop "Road Safety 365: A Workshop for Local Governments" to help local practitioners routinely identify safety issues along their roadways and provide ideas on how to address them.

Behavioral

Speeding is one of the most prevalent factors contributing to traffic crashes, and represents one area of great collaboration between transportation safety professionals from both the roadway and driver behavior areas of expertise. Speeding is also a contributing factor that affects all of the FHWA focus areas. The economic cost to society of speeding-related crashes is estimated by NHTSA to be $40.4 billion per year.

Nearly one-half of all vehicles involved in fatal crashes in 2010 were on roads with posted speed limits of 55 miles per hour or more, as compared with 19 percent of vehicles involved in injury crashes and 18 percent of vehicles involved in property-damage-only crashes. Although much of the public concern about speed-related crashes focuses on high-speed roadways, speeding is a safety concern on all roads. In 2010, about 21 percent of drivers involved in fatal crashes (10,532) were given tickets for driving too fast for conditions or in excess of posted speed limits—the highest driver factor cited for all fatal crashes. While speeding has often been seen as a prevalent occurrence on major highways, 86 percent of speeding-related fatalities occurred on roads that were not Interstate highways in 2010.

In addition to addressing opportunities for safety improvements associated with roadway design and operations, it is important to consider safety improvements associated with the drivers responsible for navigating the roadway environments.

Among drivers involved in fatal crashes, young males are the most likely to be speeding. The relative proportion of speeding-related crashes to all crashes decreases with increasing driver age. In 2010, 39 percent of male drivers in the 15- to 24-year-old age groups who were involved in fatal crashes were reported to be speeding at the time of the crash.

As shown by cases for which blood alcohol data are available, alcohol involvement is prevalent for drivers involved in speeding-related crashes. In 2010, 41 percent of drivers with a blood alcohol content (BAC) of 0.08 grams per deciliter (g/dL) or higher involved in fatal crashes were speeding, compared with only 15 percent of drivers with a BAC of 0.00 g/dL who were involved in fatal crashes. In 2010, 27 percent of the speeding drivers under age 21 who were involved in fatal crashes also had a BAC of 0.08 g/dL or higher; in contrast, only 13 percent of the nonspeeding drivers under age 21 involved in fatal crashes in 2010 had a BAC of 0.08 g/dL or higher.

Distracted driving is a behavior dangerous to drivers, passengers, and nonoccupants alike. Distraction is a specific type of inattention that occurs when drivers divert their attention from the driving task to focus on some other activity. A distraction-affected crash is any crash in which a driver was identified as distracted at the time of the crash.

In 2011, 10 percent of fatal crashes and 17 percent of injury crashes were reported as distraction-affected crashes. Of those people killed in distraction-affected crashes, 12 percent (385) died in crashes in which at least one of the drivers was using a cell phone at the time of the crash. Use of a cell phone includes talking/listening to a cell phone, dialing/texting a cell phone, and other cell-phone-related activities. Eleven percent of all drivers 15 to 19 years old involved in fatal crashes were reported as distracted at the time of the crashes. This age group has the largest proportion of drivers who were distracted. Twenty-one percent in this group were distracted by the use of cell phones. To put this in context, for all fatal crashes, only 7 percent of the drivers in the fatal crashes were 15 to 19 years old. However, for distraction, 11 percent of the drivers in fatal distraction-affected crashes were 15 to 19 years old. Likewise, drivers in their 20s were overrepresented in distraction-affected crashes relative to their proportion in total drivers—23 percent of all drivers in fatal crashes were in their 20s, but 26 percent of distracted drivers were in their 20s.

Another area of particular concern is motorcycle fatalities. While motorcycles made up 3 percent of all registered vehicles in the United States in 2011 and accounted for only 0.6 percent of all vehicle miles traveled, motorcycle fatalities accounted for 14 percent of all traffic fatalities for the year. Per vehicle mile traveled in 2011, motorcyclists were more than 30 times more likely than passenger car occupants to die in motor vehicle traffic crashes and 5 times more likely to be injured. Per registered vehicle, the fatality rate for motorcyclists in 2011 was 6 times the fatality rate for passenger car occupants. The injury rate for motorcyclists was about the same as the injury rate for passenger car occupants.

In 2011, 40 percent of fatally injured motorcycle riders and 51 percent of fatally injured motorcycle passengers were not wearing helmets at the time of the crash.

More than one-fifth of motorcycle riders (22 percent) involved in fatal crashes in 2011 were driving the vehicles with invalid licenses at the time of the collision. The percentage of motorcycle riders involved in fatal crashes in 2011 who had BAC levels of .08 g/dL or higher—29 percent—was higher than for any other type of motor vehicle driver. NHTSA estimates that helmets saved the lives of 1,617 motorcyclists in 2011. If all motorcyclists had worn helmets, an additional 703 lives could have been saved.

Transit Safety

This section describes the safety of the Nation's public transportation system. Statistics are primarily drawn from the National Transit Database (NTD). The NTD serves as a nationwide repository of transit operating, financial, service, asset, and safety data. It captures information from 47 rail transit systems, more than 650 bus transit service providers, and 1,500 demand response agencies. Combined, these modes of public transportation provided over 10 billion passenger trips and 41 billion passenger miles of service in 2010. The NTD does not collect safety data for commuter rail systems; we report FRA data for them here.

Based on the number of fatalities and injuries reported on an annual basis, public transportation generally experiences lower rates of incident, fatality, and injury than other modes of transportation in the same year. However, serious incidents do occur, and the potential for catastrophic events remains. Several transit agencies in recent years have had major accidents that resulted in fatalities, injuries, and significant property damage. The National Transportation Safety Board (NTSB) has investigated a number of these accidents and has issued reports identifying the probable causes of and factors that contributed to them. Since 2004, the NTSB has reported on nine transit accidents that, collectively, resulted in 15 fatalities, 297 injuries, and over $30 million in property damages. The NTSB identified serious deficiencies in the training and supervision of employees; the maintenance of equipment and infrastructure; and deficiencies in safety management and oversight, such as weaknesses in transit agencies' safety rules and procedures, lack of a safety culture within the transit agency, and lack of adequate oversight by the state and Federal agencies. Of the 42 safety recommendations NTSB has made to FTA since 1991, 26 of them have been addressed and closed. FTA is working diligently to address the remaining safety recommendations.

The Moving Ahead for Progress in the 21st Century (MAP-21) Act, signed into law on July 6, 2012, provides new authorities for FTA to strengthen public transportation safety throughout the United States. The law requires new safety provisions for rail and bus operators and provides grant funds to States to support enhanced oversight. FTA will implement the new law in consultation with the transit community, the State oversight agencies, and the U.S. Department of Transportation Transit Rail Advisory Committee for Safety (TRACS).

Incidents, Fatalities, and Injuries

An incident is recorded by a transit agency for a variety of events occurring on transit property or vehicles, involving transit vehicles, or affecting persons using the transit system. The Q&A box on this page provides exact reporting thresholds.

Q&A

What sort of events result in a recorded transit incident?

A transit agency records an incident for any event occurring on transit property, onboard or involving transit vehicles, or to persons using the transit system that results in one of the following:

- One or more confirmed fatalities within 30 days of the incident
- One or more injuries requiring immediate transportation away from the scene for medical attention
- Total property damage to transit property or private property in excess of $25,000
- An evacuation for life safety reasons
- A mainline derailment (i.e., occurring on a revenue service line, regardless of whether the vehicle was in service or out of service)
- A fire.

Additionally, an incident is recorded by a transit agency whenever certain security situations occur on transit property, such as:

- A robbery, burglary, or theft
- A rape
- An arrest or citation, such as for trespassing, vandalism, fare evasion, or assault
- A cyber security incident
- A hijacking
- A nonviolent civil disturbance that results in the disruption of transit service.

Included among these is any event that results in significant property damage, one or more reported injuries, one or more reported fatalities, or some combination thereof. From 2002 to 2007, the definition of significant property damage was total property damage in excess of $7,500 (in current-year dollars, not indexed to inflation); this threshold increased to $25,000 in 2008.

An injury is reported when a person has been immediately transported away from the scene of a transit incident for medical care. Any event producing a reported injury is also reported as an incident.

A transit-related fatality is reported for any death occurring within 30 days of a transit incident that is confirmed to be a result of that incident.

Q&A

What types of injuries and fatalities are reported?

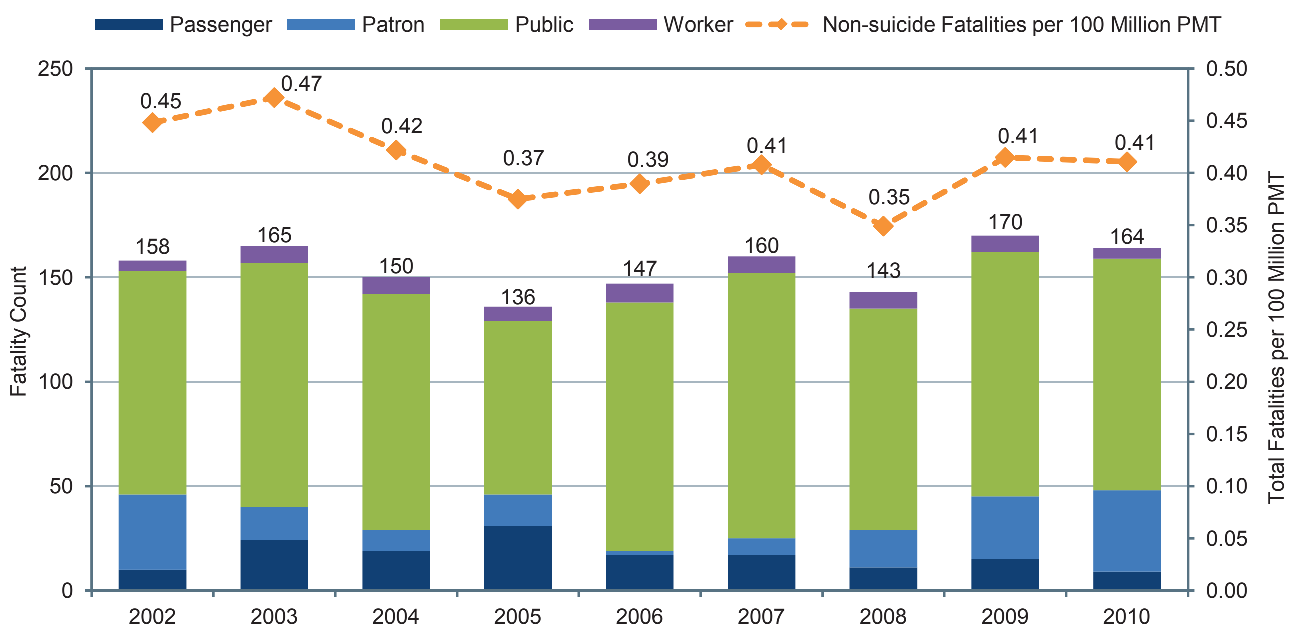
Person types are defined as:

- Passengers: Individuals on-board a transit vehicle or boarding or alighting a transit vehicle
- Patrons: Individuals waiting for or leaving transit at stations, in mezzanines, on stairs, escalators, or elevators, in parking lots and other transit-controlled property
- Public: All others who come into contact with the transit system, including pedestrians, automobile drivers, and trespassers
- Workers: Transit agency employees or contractors engaged in operations or maintenance, not construction of new transit infrastructure
- Suicides: Individuals who come into contact with the transit system intending to harm themselves

Since 2008, nationwide, collisions have resulted in about 140 fatalities per year, mostly occurring when pedestrians, bicyclists, motorists, and individuals waiting in stations, at stops, at rail grade crossings, or at intersections are struck by the transit vehicle.

Exhibit 4-10 provides data on fatalities, excluding suicides, both in total fatalities and per 100 million PMT for heavy rail, light rail, demand response, and motor bus. From 2002 to 2010, the number of fatalities has remained relatively flat while the rate per 100 million passenger miles has declined slightly due to increasing ridership. Unlike other modes, such as highway travel, public transportation has not achieved a consistent decrease in fatalities.

Exhibit 4-10 Annual Transit Fatalities Excluding Suicides, 2002–2010



Note: Exhibit includes data for DR, HR, LR, and MB. Also, fatality totals include both directly operated (DO) and purchased transportation (PT) service types.

Source: National Transit Database—Transit Safety and Security Statistics and Analysis Reporting.

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Transit interaction with pedestrians, cyclists, and motorists at rail grade crossings, pedestrian crosswalks, and intersections largely drives overall transit safety performance. The majority of fatalities and injuries in public transportation result from interaction with the public on busy city streets, from suicides, and from trespassing on transit right-of-way and facilities. Pedestrian fatalities accounted for 29 percent of all transit fatalities in 2010.

Exhibit 4-11 shows the transit fatality rate by person type between 2002 and 2010.

Exhibit 4-11 shows that workers typically account for the lowest fatality rate by person type, but that this percentage remains well above its historic level throughout the 1990s, when worker fatalities accounted for 2 percent of all transit fatalities. The NTSB also has issued a series of recommendations to support needed improvements in this area, and FTA has targeted this number with a series of new worker protection initiatives in an effort to ensure greater safety for transit workers.

Exhibit 4-11 Transit Fatality Rates by Person Type, 2002–2010, per 100 Million PMT

Year	Passenger	Patron	Public	Worker	Suicide
2002	0.03	0.10	0.30	0.01	0.04
2003	0.10	0.04	0.33	0.02	0.04
2004	0.06	0.03	0.33	0.02	0.04
2005	0.08	0.04	0.22	0.02	0.02
2006	0.05	0.01	0.31	0.02	0.03
2007	0.04	0.02	0.32	0.02	0.06
2008	0.03	0.04	0.25	0.02	0.06
2009	0.04	0.07	0.28	0.03	0.12
2010	0.02	0.09	0.27	0.01	0.13

Note: Exhibit includes data for all transit modes, excluding commuter rail.

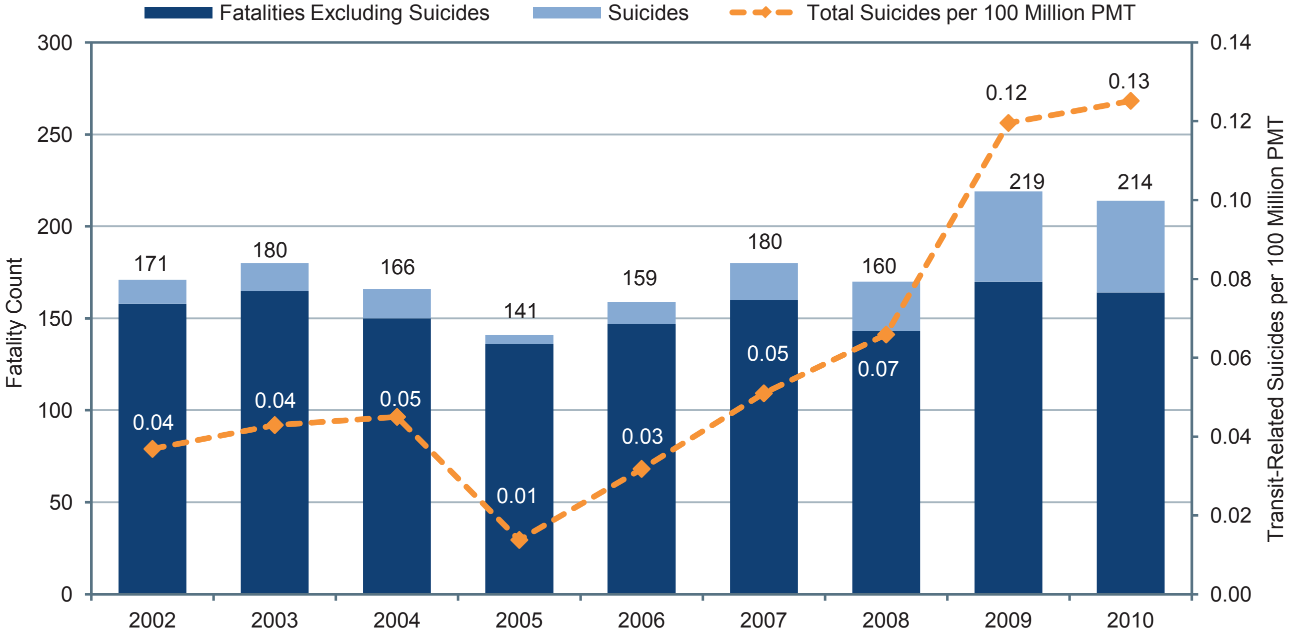
Source: National Transit Database.

Exhibit 4-11 also highlights that, although public fatalities have been decreasing in recent years, suicides have steadily increased. This change could be attributed to improvements arising from clarifications to the procedures for reporting and distinguishing between trespasser fatalities and suicides, or it could indicate a rising trend of suicides in public transportation environments. On average, fatalities involving suicides and persons who are not transit passengers or patrons (usually pedestrians and drivers) account for about 75 percent of all public transportation fatalities. This creates distinct challenges for public transportation agencies and FTA because they involve causalities which are largely outside the control of transit operators.

Many agencies and FTA are partnering with groups such as Operation Lifesaver International, universities, and local mental health agencies to devise programs to reach trespassers and suicidal individuals to attempt to change their behavior before their actions result in fatal incidents. Transit providers are working with highway agencies to address traffic problems associated with light rail and bus operations on public streets. Accident rates are expected to decline as drivers adjust to new light rail facilities and as municipalities correct roadway design features that experience multiple accidents.

Exhibit 4-12 presents fatality data for the transit industry that includes suicides. Since 2005, the number and rate of suicides has increased each year. Many transit agencies also are concerned at the recent increase in patron fatalities, largely in stations, which accounts for 18 percent of fatalities in 2010, up from a low of 4 percent in 2007.

Exhibit 4-12 **Annual Transit Fatalities Including Suicides, 2002–2010**



Note: Exhibit includes data for DR, HR, LR, and MB. Also, fatality totals include both directly operated (DO) and purchased transportation (PT) service types.

Source: National Transit Database—Transit Safety and Security Statistics and Analysis Reporting.

Exhibit 4-13, which shows transit injury rates by person type, also highlights a sharp increase in patron injury rates in recent years. Although transit incident occurrences and impacts fluctuate from year to year, it appears that transit patrons are experiencing an increased risk of fatality and injury in transit stations, stops, and mezzanines. One potential cause of this increased risk could be greater passenger crowding, particularly on rail transit modes, where this increasing patron injury trend has been reported.

Exhibit 4-13 **Transit Injury Rates by Person Type, 2002–2010, per 100 Million PMT**

Year	Passenger	Patron	Public	Worker	Suicide
2002	34.23	7.06	7.69	2.99	0.05
2003	29.93	8.85	9.90	3.29	0.03
2004	29.65	10.44	10.20	2.95	0.00
2005	28.22	9.06	8.32	2.59	0.00
2006	31.11	9.20	8.00	3.08	0.07
2007	33.32	7.35	8.74	4.72	0.04
2008*	30.34	16.89	6.86	4.03	0.04
2009	32.35	17.61	7.80	4.08	0.05
2010	35.33	13.60	8.01	3.77	0.09

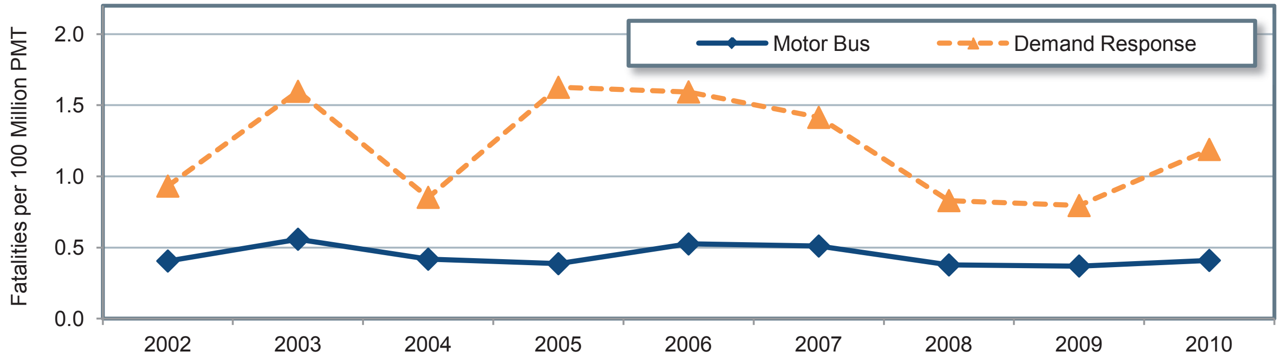
Note: Exhibit includes data for all transit modes, excluding commuter rail.

*Beginning for calendar year 2008, the reporting threshold for a reportable injury changed from two people to one person.

Source: National Transit Database.

Exhibit 4-14 shows fatality rates per 100 million PMT for motor bus and demand response (including suicides). The data show more volatility in the demand response rate, as would be expected because relatively fewer people use demand response. One or two more fatalities in a year can make the rate jump significantly. Considering this, fatality rates have not changed significantly for either mode. Absolute fatalities are not comparable across modes because of the wide range of passenger miles traveled on each mode; they are, therefore, not provided. Note that demand response fatality rates are similar to those of privately operated automobiles, which they resemble in both form and operating characteristics.

Exhibit 4-14 **Annual Transit Fatality Rates by Highway Mode, 2002–2010**

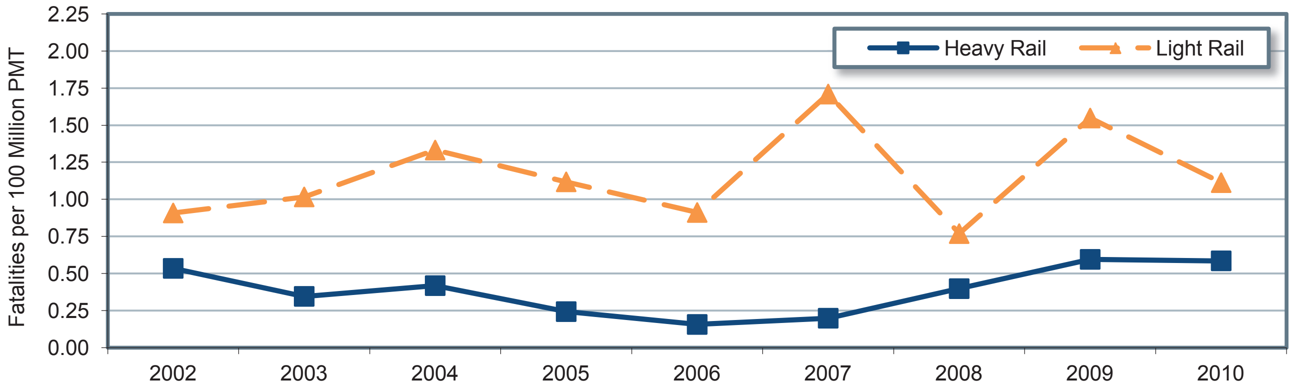


Note: Fatality totals include both DO and PT service types.

Source: National Transit Database.

Exhibit 4-15 shows fatality rates per 100 million PMT for heavy rail and light rail (including suicides). Heavy rail fatality rates were more than twice as high in 2010 as they were in 2006, although lower than they were in 2009. Of the 96 fatalities reported by heavy rail systems in 2010, 41 were classified as suicides. Light rail experiences more accidents than heavy rail because it does not usually operate on dedicated guideway and it generally picks up passengers from stops on the roadside rather than from station platforms.

Exhibit 4-15 **Annual Transit Fatality Rates by Rail Mode, 2002–2010**



Note: Fatality totals include both DO and PT service types.

Source: National Transit Database.

Exhibit 4-16 provides data on incidents and injuries per 100 million PMT for transportation services on the four largest modes reporting to the NTD from 2004 to 2010. Commuter rail data are presented separately because that data was collected according to different definitions in the FRA's Rail Accident/Incident Reporting System (RAIRS). The data in *Exhibit 4-17* suggest that the highway modes (motor bus and demand response) saw a decrease in incidents between 2004 and 2010 while they simultaneously saw an increase in injuries. This is unexplained and may be due to a change in reporting practices. Data for the rail modes is volatile, but does not suggest any significant positive or negative trends.

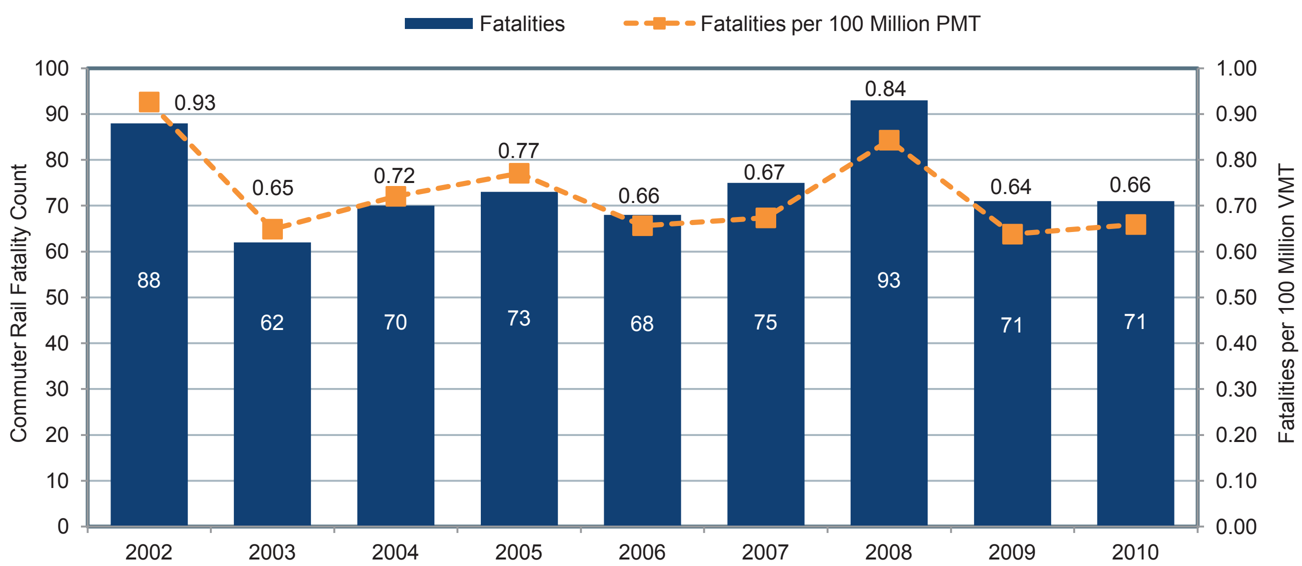
Exhibit 4-16 Transit Incidents and Injuries by Mode, 2004–2010

Analysis Parameter	2004	2005	2006	2007	2008	2009	2010
Incidents per 100 Million PMT							
Motor Bus	65.82	65.16	69.38	66.02	54.14	58.28	55.79
Heavy Rail	43.68	39.80	42.57	43.15	52.83	51.75	53.17
Light Rail	59.57	66.43	60.57	61.18	48.48	44.90	37.55
Demand Response	289.41	325.44	373.82	247.39	204.28	194.81	171.68
Injuries per 100 Million PMT							
Motor Bus	67.52	63.15	62.30	68.57	66.89	72.27	72.49
Heavy Rail	33.15	26.45	32.74	31.08	43.11	44.84	45.84
Light Rail	41.49	36.13	35.16	43.67	48.34	47.99	42.51
Demand Response	146.48	159.87	213.33	227.33	234.50	215.24	196.06

Source: National Transit Database.

Exhibit 4-17 shows both the absolute number and fatality rate per 100 million PMT for commuter rail. This data was obtained from the FRA's RAIRS. The RAIRS database records fatalities that occurred as a result of a commuter rail collision, derailment, or fire. The database also includes a category called "not otherwise classified," which includes fatalities that occurred as a result of a slip, trip, or fall. In 2011, FRA added a separate category for suicides; this data may be reported in future editions of the C&P report (suicides are not included in the data shown here). In 2010, 214 fatalities were recorded in the NTD for demand response, heavy rail, light rail, and motor bus modes, and the fatality rate per 100 million PMT (excluding suicides) was 0.41. For commuter rail, however, the absolute number of fatalities in 2010 was 71 and the fatality rate per 100 million PMT was 0.66.

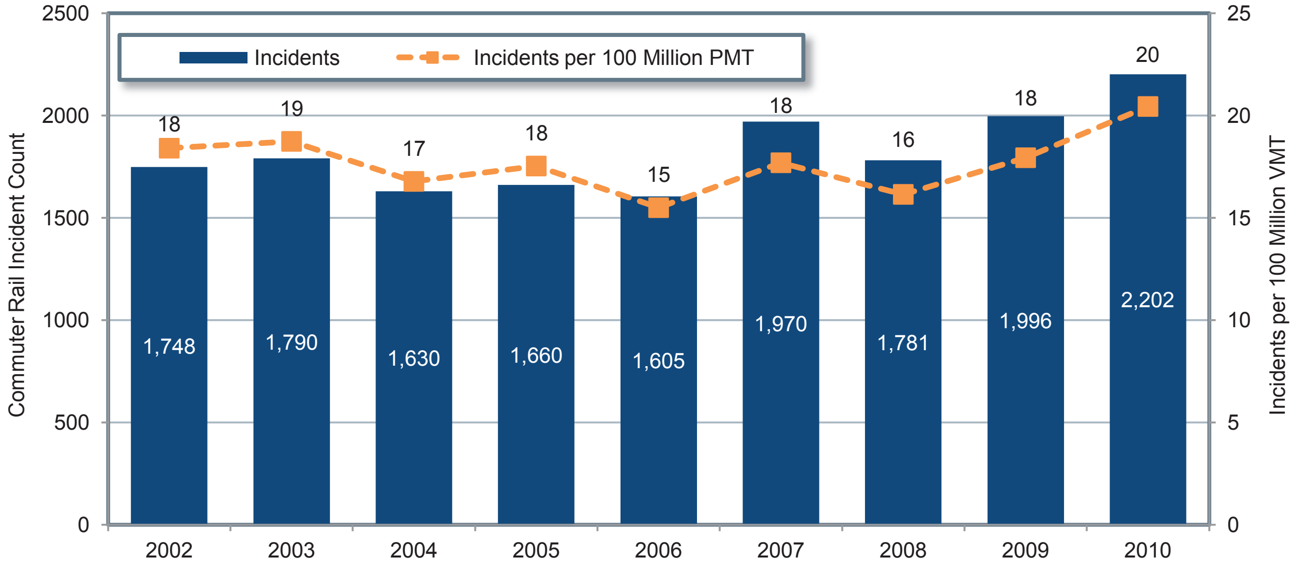
Exhibit 4-17 Commuter Rail Fatalities, 2002–2010



Source: Federal Railroad Administration Rail Accident/Incident Reporting System.

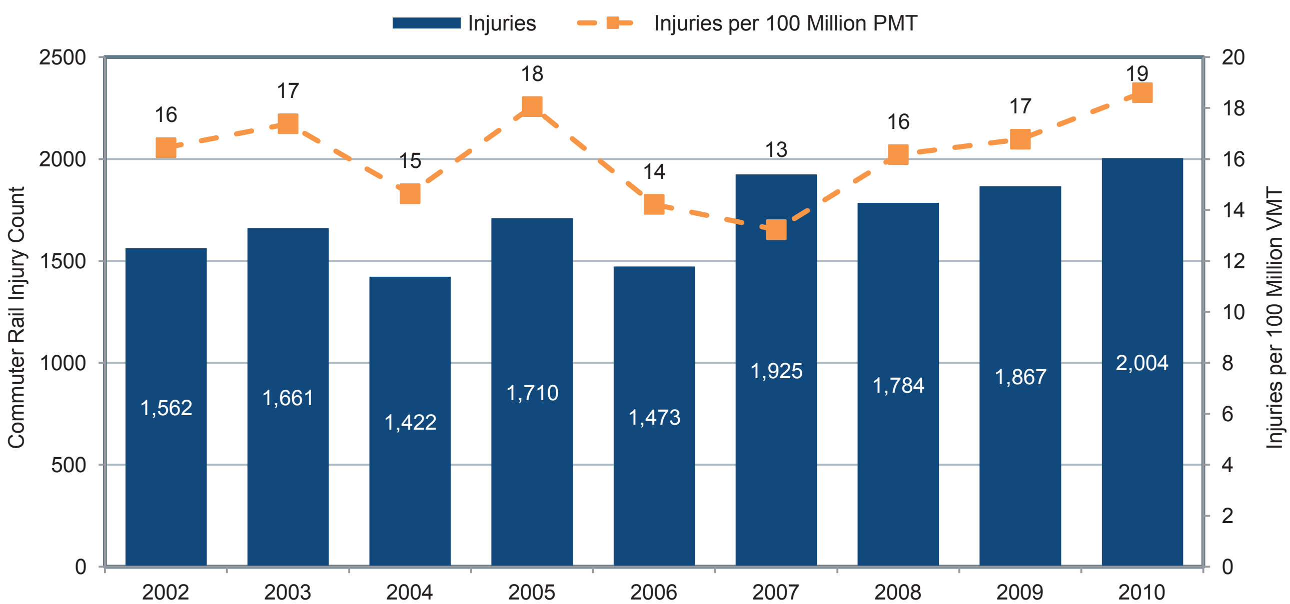
Exhibits 4-18 and *4-19* show the absolute number of commuter rail incidents and injuries per 100 million PMT, respectively. Although commuter rail has a very low number of incidents per PMT, commuter rail incidents are far more likely to result in a fatality than incidents occurring on any other mode. Most likely, this is because the average speed of commuter rail vehicles is considerably higher than the other modes (except vanpools). The number of both incidents and injuries declined from 2007 to 2008. However, between 2008 and 2010 there was a steady increase in the number of both incidents and injuries.

Exhibit 4-18 Commuter Rail Incidents, 2002–2010



Source: Federal Railroad Administration Rail Accident/Incident Reporting System.

Exhibit 4-19 Commuter Rail Injuries, 2002–2010



Source: Federal Railroad Administration Rail Accident/Incident Reporting System.

CHAPTER 5

System Performance

Highway System Performance

The transportation system provides for the movement of people and goods and influences land use and the environment around it. Transportation agencies make decisions on where to expand an existing system and where to build a new one. Increasingly, when making these decisions, the various impacts are assessed to ensure that negative ramifications on the environment are minimized, while providing a service that serves the diverse needs of its users. Many of these issues are addressed during the project development phase as directed by Federal and/or State policy.

The transportation system is best able to operate at the peak of its performance when it can support economic competitiveness at the local, regional, and national levels by providing adequate capacity and reliability, while upholding sustainability goals. Therefore, transportation agencies are being held accountable for how well they address these issues in addition to providing a system that is safe and in a state of good repair, as discussed in Chapters 3 and 4. This chapter discusses the performance of the highway system, and how sustainable transportation systems, livability, and economic competitiveness contribute to this performance. It also includes a discussion of the effect of congestion on freight travel. The U.S. Department of Transportation (DOT) Strategic Plan FY 2012–FY 2016 included the goals of reliability, economic competitiveness, livable communities, and environmental sustainability. MAP-21 also recognized the importance of developing measures for congestion reduction, system reliability, freight movement, and economic activity.

Adopting these goals and tracking performance using the new metrics could influence the type of investments made. Different highways may be selected to serve different trip purposes, e.g., freight versus a commuter trip or a local trip versus an intrastate or interstate trip. Better understanding the types of trips served by a particular roadway or mode would help in determining where to invest resources. A congested metropolitan area may provide improved transit, pedestrian, or biking facilities to take some trips off a highway in order to better serve freight trips or reduce emissions. A trade-off between the goal areas will be necessary.

U.S. DOT Strategic Goals Covered in Chapter 5

Economic Competitiveness – Promote transportation policies and investments that bring lasting and equitable economic benefits to the Nation and its citizens.

Livable Communities – Foster livable communities through place-based policies and investments that increase the transportation choices and access to transportation services.

Environmental Sustainability – Advance environmentally sustainable policies and investments that reduce carbon and other harmful emissions from transportation sources.

Transportation Systems and Livable Communities

The U.S. DOT Strategic Plan FY 2012–FY 2016 includes a goal to "Foster livable communities through place-based policies and investments that increase transportation choices and access to transportation services." Livable communities are places where transportation, housing, and commercial development investments have been coordinated so that people have access to adequate, affordable, and environmentally sustainable travel options. Incorporating livability approaches into transportation, land use, and housing policies can help improve public health and safety, lower infrastructure costs, reduce combined household transportation and housing costs, reduce growth in vehicle miles traveled, and improve air and water quality, among many other benefits.

The U.S. DOT Strategic Plan FY 2012–FY 2016 includes a separate goal to "Advance environmentally sustainable policies and investments that reduce carbon and other harmful emissions from transportation sources." Transportation is crucial to our economy and our quality of life, but building, operating, and maintaining transportation systems clearly have environmental consequences. In order to meet today's set of challenges—reducing carbon and other harmful emissions, promoting energy independence, and addressing global climate change—it is critical to foster more sustainable approaches to transportation in order to allow future generations to enjoy even higher standards of living and mobility.

Fostering Livable Communities

Designing transportation systems to balance access and mobility needs of all users is an important aspect of promoting livable communities. This includes drivers, bicyclists, pedestrians, and transit riders, among others. This approach to improving transportation systems also recognizes that each community is different and should determine what its needs are.

Transportation systems provide the foundation for how communities are formed. Deciding to build houses, schools, grocery stores, employment centers, and transit stations close to one another—while providing a well-connected street network and facilities for walking or biking—provides more transportation choices and convenient access to daily activities. It also ensures that community resources and services are used efficiently. Transportation agencies are being called upon by their stakeholders to plan, build, and operate transportation systems that support a variety of environmental, economic, and social objectives such as protecting natural resources, improving public health and safety, expanding the economy, and providing mobility. These objectives lead to a desire for a more integrated and holistic approach to planning, building, and expanding the transportation system.

Communities benefit when decisions about transportation and land use are made simultaneously. Containing development to a more compact area, allowing for mixed-use zoning, and reutilizing existing spaces or redeveloping parcels of land can reduce infrastructure costs, lower household transportation costs, preserve rural lands, reduce air and water pollution, and protect natural resources. Coordinating land use and development decisions with transportation investments can produce clear results, such as increasing viable options for people to access opportunities, goods, services, and other resources to improve quality of life.

Millwork District Project

An example of a community that has benefited from coordinated transportation and land use is the Millwork District in Dubuque, Iowa. Dubuque was challenged to reinvigorate the Millwork District, which includes the waterfront area and the Washington neighborhood, while respecting and recognizing the area's historic character. The new concept was for the District to connect the Port of Dubuque to the downtown area in order to create a thriving livable community. The Historic Millwork District was redeveloped from old factories and mills into a new mixed-use development incorporating housing, workplaces, and entertainment. Multimodal transportation improvements were made as a keystone in the strategy to bolster the community. Expanding the District's transportation options attracted both businesses and residents of the area.

The project made use of cost-effective and sustainable practices, such as reusing brick pavers and installing energy-efficient street lights. It also created jobs and capitalized on local resources by using locally manufactured benches, bike racks, and trash receptacles. As a result of the Millwork District project, new streets are now accessible to all road users regardless of age or ability. The once-empty warehouses and idle mills have become popular shops, employment centers, and homes. The Millwork District is now a vibrant community, building on the past that has transformed into a more livable community. The U.S. DOT awarded a $5.6-million Transportation Investment Generating Economic Recovery (TIGER) Discretionary grant to Dubuque, Iowa, for revitalization of the Millwork District. Federal dollars are helping the city leverage millions more in additional investments for a total of $7.7 million.

Addressing livability issues in transportation ensures that transportation investments support both mobility and broader community goals. A well-designed transportation system can be the catalyst for achieving a range of community and regional goals including economic growth, job creation, goods movement, and access to education and health care. Transportation also contributes to increased quality of life for residents and helps maintain the Nation's role in a global economy. As will be discussed later in this chapter, freight movement is an essential part to moving goods and building stronger economies and, when carefully planned, it helps reduce congestion and fosters livable communities. Communities can be aesthetically pleasing, safe, and walkable, while still providing efficient access for large trucks, rail lines, and other modes of transportation.

There is a growing demand to design facilities for all users, while balancing the different access and mobility needs of motorists, truckers, bicyclists, pedestrians, and transit riders. The ability of transportation networks to connect and function, support regional economies, and protect environmental and public health is becoming increasingly relevant to long-term economic prosperity and community quality of life. Additional information on the characteristics of livability and the benefits of livable communities can be found in Chapter 13 of the 2010 C&P Report and at the U.S. DOT Livability website at www.dot.gov/livability.

Philadelphia Area Pedestrian Bicycle Network

In Philadelphia, PA, the area pedestrian and bicycle network spans 128 miles connecting six counties around Philadelphia and Southern NJ. U.S. DOT TIGER funds are being used to repair and improve 16 miles of the network on well-used commuter routes to downtown and in economically distressed neighborhoods in Philadelphia and Camden, NJ.

Measuring Livability

Measuring the impact of transportation investments on livability is an ongoing effort. The U.S. DOT Strategic Plan FY 2012–FY 2016 emphasizes the importance of adopting a comprehensive, coordinated, and performance-based approach to enhancing livability and evaluating transportation investments. As previously mentioned, in support of this coordinated outcome-driven approach, the U.S. DOT Strategic Plan establishes as one of five strategic goals "fostering livable communities through place-based policies and investment that increase transportation choices and access to transportation services." This Livable Communities strategic goal is supported by three outcome-based objectives, shared among the Federal Highway Administration (FHWA), the Federal Transit Administration (FTA), and the Federal Railroad Administration (FRA):

1. Increased access to convenient and affordable transportation choices
2. Improved networks that accommodate pedestrians and bicycles
3. Improved access to transportation for people with disabilities and older adults.

Livable Communities Outcomes and Performance Measures

FHWA focuses on two of the three outcomes, and is tracking them by State using performance measures:

- **Outcome:** Improved networks that accommodate pedestrians and bicycles.
  Performance Measure: Increase the number of States that have policies that improve transportation choices for walking, wheeling, and bicycling. In FY2011, the target was 22 States and the actual was 24; in FY2012, the target was 26, increasing to 27 by FY2013.
- **Outcome**: Improved access to transportation for people with disabilities and older adults.
  Performance Measure: Increase the number of States that have developed an Americans with Disabilities Act (ADA) transition plan that is current and includes public rights-of-way. In FY2011, the target was nine States and the actual was 13; in FY2012, the target was 13, increasing to 15 by FY2013.

The Interagency Partnership for Sustainable Communities, a joint initiative of the U.S. Department of Housing and Urban Development, U.S. DOT, and U.S. Environmental Protection Agency (EPA), is working to share information about how communities can track performance. In addition, FHWA is examining ways that communities can gauge whether their programs, policies, and projects are making a positive impact on quality of life. *Exhibit 5-1* lists examples of measures that communities could consider.

Exhibit 5-1 **Potential Livability Performance Measures**

Accessibility	Economic	Housing	Land Use	Public Health	Safety
Annual public transportation passenger miles per capita Annual public transportation trips per capita Availability of bicycle parking Average commute distances	Access to jobs and markets for disadvantaged populations compared to entire population Access to personal vehicle, by age, race, income, and location Average number of employment opportunities within a given number of miles of a transit stop	Acres of land consumed per residential unit Average commute distances Average energy efficiency rating of homes Average number of full-service super-markets within a given number of miles or minutes	Acreage of agricultural lands disturbed Acreage of habitat consumed/ habitat fragmentation index Acreage of high-quality wetlands Acreage of land consumed per lane mile Acreage of sensitive lands/important habitats impacted/ consumed	Air quality conformity status Ambient air quality Amount and percent change in greenery and open space Average commute distances	Barriers to pedestrians and cyclists Average speed of emergency vehicles on emergency calls Pedestrian crash fatality rate Number/ percent of people living in substandard residential units

The U.S. EPA has also identified 12 sustainable transportation performance measures in its Guide to Sustainable Transportation Performance Measures (http://www.epa.gov/dced/transpo_performance.htm). The guidebook describes the 12 measures that can readily be applied in transportation decision-making. It also presents possible metrics, summarizes the relevant analytical methods and data sources, and illustrates the use of each measure.

Sustainable Transportation Performance Measures

- Transit Accessibility
- Bicycle and Pedestrian Mode Share
- Vehicle Miles Travelled per Capita
- Carbon Intensity
- Mixed Land Use
- Transportation Affordability
- Benefits by Income Group
- Land Consumption
- Bicycle and Pedestrian Activity and Safety
- Bicycle and Pedestrian Level of Service
- Average Vehicle Occupancy
- Transit Productivity

Multimodal Transportation and Livability

One of the key efforts of the U.S. DOT livability initiative is to promote safe, affordable, and convenient transportation choices. Across the country, States and communities are focusing renewed attention on improving transportation facilities for walking and bicycling. This is evident in the use of Federal-aid funds for walking and bicycling projects. The highest level of Federal-aid investment on record for nonmotorized facilities was achieved in FYs 2009, 2010, and 2011 ($1.19 billion, $1.04 billion, and $790 million, respectively). SAFETEA-LU created two new programs that specifically focused on walking and bicycling: the Nonmotorized Transportation Pilot Program (NTPP) and the Safe Routes to School (SRTS) Program. The programs have explored how communities can improve safety and transportation choices with increased investment in walking and bicycling.

The NTPP provides a glimpse at what happens when communities increase their investment in walking and bicycling transportation facilities. SAFETEA-LU specified that four communities—Marin County, CA; Columbia, MO; Sheboygan County, WI; and Minneapolis, MN—would each receive $25 million to improve their walking and bicycling transportation networks. The FHWA was tasked with reporting on the outcomes of this investment in a Report to Congress (see http://www.fhwa.dot.gov/environment/bicycle_pedestrian/ntpp/2012_report/). This report documents the changes in transportation use and estimated changes in several key factors including safety and emissions as well. Among the key findings are that counts of walkers and bicyclists increased an average of 49 percent and 22 percent, respectively. An estimated 16 million miles were walked and bicycled in the communities in 2010 and it is estimated that the pilot communities saved 22 pounds of CO_2 in 2010 per person, or a total of 7,710 tons, due to replacing personal vehicle trips with walking and bicycling. Despite notable increases in walking and bicycling, fatal bicycle and pedestrian crashes remained steady, indicating that safety has not been adversely affected.

On the other hand, the SRTS Program has provided funds to each State by a formula based on each State's population of children in kindergarten through eighth grade. The SRTS Program, a $612-million program over 5 years, has supported infrastructure and noninfrastructure (e.g., safety education) activities and required that each State have an SRTS Coordinator. As of August 2011, over 10,400 schools in all 50 states and the District of Columbia, have been involved in the program (see http://www.saferoutesinfo.org/sites/default/files/resources/progress%20report_FINAL_web.pdf). So far the most common use of funds has been sidewalk improvements (19 percent), followed by traffic calming (14 percent) and education (14 percent). In sum, estimates are that over 4.8 million students may benefit from the transportation improvements near their schools.

Although the two SAFETEA-LU programs have taken different approaches (e.g., providing funding to specific communities versus distributing funds to all States), they both demonstrate the national interest in walking and bicycling transportation. Based on recent demographic changes, which indicate that adults under age 30 are driving less, it will be even more important to provide safe, convenient, and affordable transportation options for people of all ages and abilities (see http://www.fhwa.dot.gov/policy/otps/nextgen_htps_scan.htm).

Advancing Environmental Sustainability

The 1987 United Nations (UN) World Commission on Environment and Development defined sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." While a number of other definitions for sustainability have emerged, a concept often used is the "triple bottom line," referring to environmental, social, and economic principles. In transportation, the triple bottom line relates to sustainable solutions for the natural environment, the economic efficiency of the system, and societal needs for those using the system (e.g., mobility, accessibility, and safety). Transportation agencies can address sustainability through a wide range of initiatives, such as Intelligent Transportation Systems, livability, smart growth, planning and environment linkages, and addressing requirements of the National Environmental Policy Act (NEPA).

From an environmental sustainability perspective, the heavy reliance of the transportation system on fossil fuels is a significant concern. Fossil fuels are non-renewable; generate air pollution; and contribute to the buildup of carbon dioxide (CO_2) and other greenhouse gases (GHGs), which trap heat in the Earth's atmosphere. Although some progress has been made in reducing emissions of air pollutants both nationally and from the transportation sector in particular, many Americans continue to live in regions that do not meet health-based air-quality standards. Through oversight of the Clean Air Act "conformity" requirements, FHWA helps to ensure that these regions continue to make progress toward their air-quality standards.

Projects funded through the Congestion Mitigation and Air Quality Improvement program (CMAQ) contribute to emissions reductions in these regions. FHWA also promotes potential strategies to reduce GHG emissions, through improving system efficiency, reducing VMT, and transitioning to fuel-efficient vehicles and alternative fuels. FHWA supports research related to these strategies, provides technical assistance to stakeholders, and coordinates its activities within U.S. DOT and with other Federal agencies.

Beyond strategies to reduce emissions, the transportation community is beginning to focus its efforts on anticipating future extreme weather events and changes in climate (e.g., higher sea levels, increased temperatures, altered precipitation patterns, greater storm intensity) and the potential impact of these changes on the transportation system (e.g., damaged or flooded facilities). For a transportation system to be sustainable, it must be able to adapt to future as well as present conditions. Research efforts regarding the potential impacts of climate change on transportation infrastructure are ongoing at the Federal, State, and local levels. The U.S. DOT released a report on projected changes in climate over the next century, used geographical information systems to map areas with transportation infrastructure along the Atlantic coast that will be potentially vulnerable to sea level rise, and is conducting a second adaptation study focused on the Gulf Coast region. These studies identify potential climate change impacts that are widespread and modally diverse and that would stress transportation systems in ways beyond which they were designed. FHWA has developed a flexible framework to assist transportation agencies in adapting to the impacts of climate change that starts with inventorying critical infrastructure, understanding potential future climate change impacts, and assessing vulnerabilities and risks.

Adaptation Pilots

In autumn of 2010, FHWA funded five State areas' DOTs and Metropolitan Planning Organizations to pilot a draft framework for conducting vulnerability and risk assessments of transportation infrastructure given the projected impacts of climate change. Each area's approach was different and contributed significantly to its understanding of potential climate change impacts on its transportation assets, and to the body of knowledge of the transportation community as a whole. FHWA is currently using the experiences of these five pilots and other studies to update the draft framework and expand it with "in-practice" examples.

The **Washington** DOT (WSDOT) assessed the infrastructure it owns, including roads, rail, ferry facilities, and airports. In internal workshops around the State, they developed criticality and impact ratings for each asset, which they used to create vulnerability maps for each region.

An interagency group in **New Jersey**, led by the North Jersey Transportation Planning Authority, closely followed the three steps of FHWA's framework in its analysis of the New Jersey Turnpike/I-95 corridor and the New Jersey Coast. It worked closely with the State climatologist to downscale climate model projections to New Jersey, estimating future changes to the 100-year floodplain due to heavier rainfall resulting from climate change. In addition, the interagency group worked with the New Jersey Department of Environmental Protection to create estimates of relative sea level rise. To identify facilities vulnerable to the effects of sea level rise, storm surge, and inland flooding, it used geographic information systems to determine intersections between inundated areas and transportation assets.

The **Oahu** Metropolitan Planning Organization used an interagency, multidisciplinary, 2-day workshop to facilitate a climate change dialogue and identify five key groups of vulnerable transportation assets for further study. The five groups of assets, based on geographic areas, were then analyzed in more detail by transportation experts in three full-day work sessions, resulting in a detailed qualitative risk assessment for each asset.

The University of **Virginia**'s Center for Transportation developed a priority-setting tool to assess how consideration of climate change and other factors may affect project prioritization in a transportation plan. It used the Hampton Roads region as a case study and made the model available for use by other regions.

The Metropolitan Transportation Commission, in partnership with the **San Francisco Bay** Conservation and Development Commission and others, led a study of a portion of the San Francisco Bay stretching from the Oakland Bay Bridge to the San Mateo Bridge (Alameda County). This study was focused on sea level rise. The project team developed profiles of risk from the effects of sea level rise, including exposure, sensitivity, and adaptive capacity for a representative list of roads, transit, facility, and pedestrian and bicycle transportation assets within the study area.

Additional information on sustainability and climate change can be found in Chapters 11 and 12 of the 2010 C&P Report, and at FHWA's sustainable transport and climate change websites at http://www.fhwa.dot.gov/environment/climate_change and at http://www.sustainablehighways.dot.gov.

Measuring Sustainability

Using sustainability as a metric generally means an expansion of traditional measurement frameworks to take into account the triple bottom line of social, environmental, and economic performance. Many organizations are developing organization-specific or industry-specific measurement tools and best practices to help them achieve the appropriate balance among social, environmental, and economic principles.

At the Federal level, environmental sustainability has been adopted as a strategic goal in the U.S. DOT Strategic Plan FY 2012–FY 2016. At the State level, transportation agencies are developing metrics that address various aspects of sustainability and are monitoring progress toward specific goals—often in their long-range and project-level planning process. Some potential measures that have been identified for assessing progress in improving sustainability relate to reducing GHG emissions, improving system efficiency, reducing the growth of VMT, transitioning to fuel-efficient vehicles and alternative fuels, and increasing the use of recycled materials in transportation.

FHWA's INVEST Sustainability Self-Evaluation Tool

The FHWA has launched an initiative to support transportation agencies in making highway projects and programs more sustainable. This new initiative features a voluntary web-based self-evaluation tool, the Infrastructure Voluntary Evaluation Sustainability Tool (INVEST). In addition to measuring the sustainability of a project or program, INVEST can enable transportation agencies to:

- **Evaluate Sustainability Trade-Offs.** INVEST can help users better evaluate sustainability tradeoffs. Every highway project involves tradeoffs, and decisions often become more difficult when two or more options are not directly comparable. INVEST can help with these decisions by assigning points to various criteria based on their sustainability impacts.
- **Find and Address Programmatic Barriers.** Measuring sustainability on a program, project, or group of projects can enhance an agency's ability to identify programmatic barriers that they encounter so they can be addressed and removed. These barriers might be the result of policies, design standards and specifications, or stakeholder agency policies.
- **Communicate Benefits and Goals.** Measuring sustainability and reporting results allows transportation organizations to communicate sustainability goals and benefits to stakeholders.

More information on INVEST can be found at www.sustainablehighways.org.

Economic Competitiveness

The U.S. DOT Strategic Plan FY 2012–FY 2016 includes a goal to "Promote transportation policies and investments that bring lasting and equitable economic benefits to the Nation and its citizens."

Maintaining economic competitiveness means increasing and maximizing the contribution of the transportation system to economic growth. At the same time, such investments help accomplish other strategic goals, because maximizing economic benefits requires consideration of the safety, asset management, livability, personal and freight mobility, and environmental sustainability of the entire transportation network. Economic competitiveness will also require implementation of new technologies that enable people and goods to move more efficiently and fully utilize existing capacity across all modes. This section presents information on various aspects of a highway transportation system that affect economic competitiveness.

System Reliability

Reliability is an important characteristic of any transportation system, one that industry in particular requires for efficient production. American manufacturers are increasingly shifting production to high-value, high-tech products whose manufacture integrates transportation into a just-in-time supply chain based on efficient performance and consistent reliability. Additional emphasis will be placed on the American freight network as more manufactured products will need to move across the country. Imported goods shipped to ports will also increase as the American economy continues to grow. Freight shippers, a substantial portion of the nation's economy, depend on a predictable and reliable system to move goods across regions. Although industry may budget for extra time for congestion, unexpected travel delays cannot be accounted for. If industry is unable to utilize a reliable system, they may be required to carry greater inventory than would otherwise be necessary, thereby incurring higher costs.

Travel time reliability is a measure of congestion easily understood by a wide variety of audiences, and is one of the more direct measures of the effects of congestion on the highway user. Before travel time reliability, simple averages were mostly used to explain traffic congestion. However, most travelers experience and remember something much different than a simple average throughout a year of commutes. Their travel times vary greatly from day to day, and they remember those few bad days they suffered through unexpected delays. If unexpected delays are minimized in a given period, all users are able to adequately plan for the best use of their time while moving through the transportation network.

Many transportation reliability measures exist, with varying levels of utility. Such measures typically compare high-delay days with average-delay days. The simplest method identifies days that exceed the 90th or 95th percentile in terms of travel times and estimates the severity of delay on specific routes during the worst one or two travel days each month. Another method, the Buffer Index, measures the percentage of extra time travelers must add to their average peak-hour travel time to allow for congestion delays and arrive at a location on time about 95 percent of the time. Generally, the Buffer Index goes up during peak periods—when congestion occurs—indicating a reliability problem.

FHWA Urban Congestion Report

The Urban Congestion Report (UCR) is produced quarterly and characterizes traffic congestion and reliability at the national and city levels. The reports utilize archived traffic operations data gathered from State DOTs and through a public-private partnership with a traffic information company and reflect data from 19 urban areas in the Nation. The production of these reports is a cooperative effort between the Texas Transportation Institute and FHWA. The UCR data are also being used to report Travel Time Reliability in metropolitan areas for the FHWA Strategic Plan, which is available at http://www.fhwa.dot.gov/policy/fhplan.html#measurement.

The congestion information presented in these reports may not be representative of the entire roadway system in any particular city because the UCR includes only those roadways that are instrumented with traffic sensors for the purposes of real-time traffic management and/or traveler information. Construction may affect the roadways that are included in this report. The congestion and reliability trends are calculated by comparing the most recent 3 months of the current year to the same 3 months of the prior year.

Data from April through June 2012 concluded that the average duration of weekday congestion is 1 minute longer than in 2011 at 4 hours and 23 minutes per day (during the hours of 6 a.m. to 10 p.m.). Further information can be found at http://ops.fhwa.dot.gov/perf_measurement/ucr/.

System Congestion

Congestion results when traffic demand approaches or exceeds the available capacity of the system. "Recurring" congestion occurs in roughly the same place and time on the same days of the week, and occurs when the physical infrastructure is not adequate to accommodate demand during peak periods. Nonrecurring congestion is caused by temporary disruptions that take away part of the roadway from use. The three main causes of nonrecurring congestion are: incidents ranging from a flat tire to an overturned hazardous material truck (25 percent of total congestion), work zones (10 percent of total congestion), and weather (15 percent of total congestion). Nonrecurring congestion accounts for about half of the congestion on roadways.

Congestion leads to delays, and variability in congestion can lead to or exacerbate reliability problems. Therefore, measuring congestion is very much linked to measuring reliability. There is no universally accepted definition or measurement of exactly what constitutes a congestion "problem." The perception of what constitutes a congestion problem varies from place to place. Traffic conditions that may be considered a congestion problem in a city of 300,000 may be perceived differently in a city of 3 million, based on differing congestion histories and driver expectations. These differences of opinion make it difficult to arrive at a consensus of what congestion means, the effect it has on the public, its costs, how to measure it, and how best to correct or reduce it. Because of this uncertainty, transportation professionals examine congestion from several perspectives.

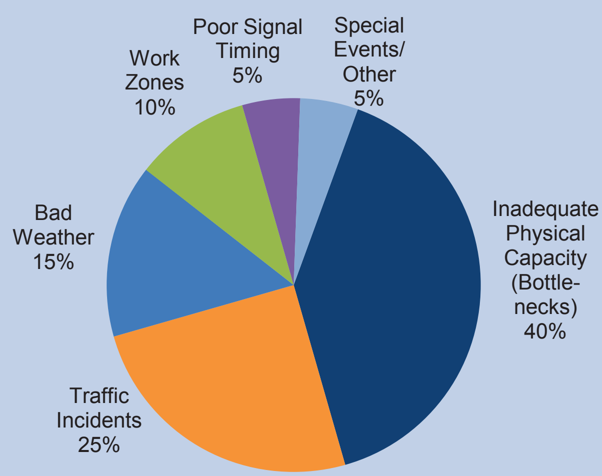
Three key aspects of congestion are severity, extent, and duration. The **severity** of congestion refers to the magnitude of the problem or the degree of congestion experienced by drivers. The **extent** of congestion is defined by the geographic area or number of people affected. The **duration** of congestion is the length of time that the roadway is congested.

Causes of Congestion

The process of congestion relief begins with an understanding of the problem. The various sources of congestion, detailed in *Exhibit 5-2*, frequently interact, meaning that mitigation strategies typically address more than one problem.

- Inadequate capacity: the roadway does not have adequate capacity to efficiently move the number of vehicles traveling on it.
- Bottlenecks: points where the roadway narrows or regular traffic demands cause traffic to backup.
- Traffic incidents: crashes, stalled vehicles, and debris on the road cause about one-fourth of congestion problems.
- Work zones: new road building, rehabilitation, preservation, and maintenance activities are necessary, but the amount of congestion caused by these actions can be reduced by a variety of strategies.
- Bad weather: cannot be controlled, but travelers can be notified of the potential for increased congestion.
- Poor traffic signal timing: the faulty operation of traffic signals where the time allocation for a signal does not match the traffic volume on that road is a source of congestion on some major and minor streets.
- Special events that cause spikes in traffic volume and changes in traffic patterns: irregularities cause delay on days, at times, or in locations where there usually is none, or add to regular congestion problems.

Exhibit 5-2 Sources of Congestion



Source: Federal Highway Administration http://www.fhwa.dot.gov/congestion/describing_problem.htm.

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